BLM LIBRARY
88069843

SALT PRODUCTION FROM MICRO-CHANNELS IN THE PRICE RIVER BASIN, UTAH

by

Richard Bruce White

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Civil and Environmental Engineering

UTAH STATE UNIVERSITY
Logan, Utah

1977

TN
902
.U8
W45
1977
c.2

#16415402 ID 88069843

TN
902
.U8
W45
1977

SALT PRODUCTION FROM MICRO-CHANNELS IN THE PRICE RIVER BASIN, UTAH

by

Richard Bruce White

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Civil and Environmental Engineering

Approved:

Richard W. Hansen
Major Professor

R. E. T. Nelson
Committee Member

Gerald T. Sifford
Committee Member

Paul Riley
Committee Member

Committee Member

Eastman V. Stark
Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

1977

BUREAU OF LAND MANAGEMENT LIBRARY
BLDG. 50,
DENVER FEDERAL CENTER
P.O. BOX 25047
DENVER, COLORADO 80225

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	iii
LIST OF TABLES	iv
LIST OF FIGURES	vi
ABSTRACT	viii
INTRODUCTION	1
Importance of Study	1
Study Objectives	2
STUDY AREA	3
General	3
Geology	5
Soils	10
Climate	10
Streamflow	16
LITERATURE REVIEW	18
Gully Processes	18
Price River Basin Diffuse Source Salinity	22
METHODS	27
Site Selection	27
Hydrology and Water Quality	30
Natural Variability	36
RESULTS AND DISCUSSION	38
Natural Variability	38
Hydrology	45
Water Quality	50
CONCLUSIONS	83
RECOMMENDATIONS FOR FURTHER RESEARCH	87
LITERATURE CITED	89
APPENDIXES	95
VITA	121

ACKNOWLEDGEMENTS

It is always difficult to extend appreciation to those who have been instrumental in one's success because of the awkwardness of words and the fear of forgetting someone. I must, however, mention a few people and hope that they understand my gratitude.

First, and foremost, I am extremely appreciative of my wife, Kathrine, for her patience and support during the process of obtaining the MS degree. Her help in typing the thesis has been very important to me.

A word of gratitude is also extended to Dr. Richard H. Hawkins, who served as my major Professor and provided much of the needed technical and moral support. His time was always given freely.

I wish to express my gratitude to Dr. Gerald F. Gifford for his meaningful and constructive criticism of the thesis, Drs. Jerome J. Jurinak and Peter T. Kolesar for their technical advise, and Dr. J. Paul Riley for the aid in making the transition from student to hydrologist. The help provided by the project technicians, James W. Smith and Charles P. Felice, in data collection, analysis, and preparation is also greatly appreciated.

I am also indebted to the US Bureau of Land Management for providing the funds for research and the continuance of my education through contract number 52500-CT5-16 (N).

Richard B. White

LIST OF TABLES

Table		Page
1.	Population trends in Carbon County, Utah Since 1910 . . .	5
2.	Stratigraphic units present at the surface in the Price River basin (from Ponce, 1975)	8
3.	Mean monthly and annual temperature and precipitation for stations in the Price River basin (from the Utah Division of Water Resources, 1975)	13
4.	Long-term mean discharge at selected stations in the Price River basin (from Mundorff, 1972)	16
5.	Description of channels sampled during the Price River basin micro-channel study	29
6.	Analyses completed on water samples collected during the micro-channel study	34
7.	Means and standard deviations of EC measurements from 1:1 soil extracts of samples taken from channels 1-3, 2-3, and 3-3 (channel homogeneity test)	40
8.	Results of t-tests for comparisons of one-to-one soil extract electrical conductivities of samples taken from various locations within channels 1-3, 2-3, and 3-3 . . .	42
9.	Summary of size fraction analyses of soil samples collected prior to selected runs	47
10.	Results of storm frequency analyses for each channel and run	49
11.	Results of linear regression analyses (Y = A + BX) of electrical conductivity versus total dissolved solids, suspended solids versus total dissolved solids, and electrical conductivity versus suspended solids for run number one in all channels	54
12.	Results of linear regression analyses (Y = A + BX) of average electrical conductivity versus average ionic concentration at the 100 foot (30 m) station of all channels during all runs	56

LIST OF TABLES (continued)

Table — Page

13. Salt loads per unit flow volume and total dissolved solids concentrations of composite one-to-one extracts of soil samples collected prior to runs for each channel and run at sites 1, 2, and 3. The indicated salt load is the total amount produced at the 100 foot (30 m) station within 30 minutes 61

14. Results of linear regressions through the origin (Y = BX) of accumulated sediment (X) versus accumulated salt (Y) for all channels and runs 66

15. B value summarization for various channels, sites, and geologic types in the Price River basin 70

16. Salt-sediment ratios resulting from overland flow on soil of various geologic origins in the Price River basin (from Ponce, 1975) 71

17. Salt-sediment ratios resulting from storm runoff events in major channels in the Price River basin (from Mundorff, 1972) 72

18. Average 30 minute salt load and concentration for micro-watersheds seven through nine (from Ponce, 1975) and channel 1-2. Values are averaged over all runs and corrected for differences in storm sizes 77

19. Estimated annual sediment and salt yields from Mancos shale lands in the Price River basin due to micro-channels 81

20. Electrical conductivity, in μmhos/cm at 25°C, of one-to-one extracts of samples collected for the channel homogeneity test. The locations given are when facing downstream . . 108

21. Results of size fraction analyses of selected pre-run soil samples 110

22. Results of chemical analyses of selected water samples collected during the micro-channel study, corrected for control 117

LIST OF FIGURES

Figure — Page

1. The Price River basin of east-central Utah (1 mile = 1.61 km) 4
2. Major stratigraphic units present in the Price River basin (from Ponce et al., 1975) 7
3. Extent of published soil surveys within the Price River basin 11
4. Soil associations in the central portion of the Price River basin (from Mundorff, 1972; 1 mile = 1.61 km) . . . 12
5. Mean monthly temperature and precipitation at Scofield Dam and Price Game Farm ($^{o}C = (^{o}F-32)\ (5/9)$; 1 inch = 25.4 mm). 14
6. Micro-channel study site locations within the Price River basin (1 mile = 1.61 km) 28
7. Field layout of micro-channel study site number one . . . 31
8. Soil sample locations for channel homogeneity test (looking downstream) 36
9. Electrical conductivity of one-to-one soil extracts versus downstream distance for channel 1-3 at the 0 to 1 inch (0-25 mm) and 1 to 6 inch (25-150 mm) depths 39
10. Variation in the salinity of a channel bank downstream from site one 44
11. Inflow and outflow hydrographs for (a) channel 1-2, run number 3 and (b) channel 4-1, run number 1 46
12. Average ionic concentration at the 100 foot (30 m) station during run number one in all channels during the first 30 minutes of flow 51
13. Suspended solids and total dissolved solids concentrations through time for channel 1-1, run number 1 57
14. Effects of flow distance on total dissolved solids concentration for channels 1-2 (run 2), 2-1 (run 1), and 3-2 (run 1) 60

LIST OF FIGURES (Continued)

Figure		Page
15.	Effects of flow parameters on salt loads resulting from each run in each channel	63
16.	Effects of channel parameters on salt loads resulting from each run in each channel	64
17.	Accumulated sediment versus accumulated salt for channels 1-1 and 2-1, run number 3	67
18.	Effects on B of commonly measured values of average percent clay and electrical conductivity of the one-to-one soil extract of the channel bottom	75
19.	Boundary conditions for the use of equation (7)	76
20.	Measurements taken along the channel following each run for the determination of various flow parameters	106
21.	Intensity-duration curves for the infiltration excess model	114

ABSTRACT

Salt Production From Micro-channels

In the Price River Basin, Utah

by

Richard B. White, Master of Science

Utah State University, 1977

Major Professor: Dr. Richard H. Hawkins
Department: Civil and Environmental Engineering

Salt production from micro-channels in the Price River basin of east-central Utah was studied using artificial inputs in order to better define the general sources and processes involved in diffuse source salt release within the basin. An attempt was made to determine what factors are most significant in relation to salt release.

The study revealed that the micro-channel systems are highly heterogeneous in relation to salinity. This natural variability tends to increase as the salt content of the channel increases.

The Bluegate member of the Mancos shale was found to be the prime source of salt within the basin. Gypsum was the most prevalent salt encountered. Electrical conductivity was seen to be a significant index of salt and sediment production.

Both suspended solids and total dissolved solids concentrations were observed to increase with distance downstream and decrease with time. A period of quasiequilibrium of concentrations was reached approximately 20 or 25 minutes after the beginning of a run. This was theorized to be the time required for the loose, easily eroded material to be washed away from the surface of the channel. A distance

related equilibrium was reached after approximately 800 or 1000 feet (240 or 300 m) of flow length.

Salts loads were found to be relatively insensitive to channel and flow parameters but very sensitive to suspended sediment loads. This suggested that the same processes involved in sediment release also act in the release of salt. A prediction equation was developed to determine the ratio of salt to sediment resulting from some event.

Micro-channels are suspected of yielding seven to ten times the salt concentration and load resulting from overland flow. It was estimated that approximately 3.4 percent of the salt which annually passes Woodside is the result of micro-channel activity.

(130 pages)

INTRODUCTION

Recent research by Mundorff (1972), Blackman et al. (1973), and others has shown that the Price River basin of east-central Utah is an important source of salinity within the Colorado River basin. Because of the international nature of the Colorado River, this production of salt has been an important concern for both the United States of America and the Republic of Mexico (see Office of Public Services, 1962; 1972; and 1975). In an effort to pinpoint the processes and general contributing areas of salt production from diffuse sources in the Price River basin, research funds have been provided by the U.S. Bureau of Land Management (BLM). The first of these research efforts (Ponce, 1975) dealt with the salinity associated with overland flow. From this study it was estimated that a very small portion (approximately 0.5 percent) of the total salt mass which annually leaves the Price River basin results from direct pickup due to overland flow. Whitmore (1976) concurrently studied the mechanisms involved in salt release from Mancos derived soils. In order to better define the production of salt from non-point sources in the Price River basin, attention has been turned towards the micro-channels "downslope" from the overland flow plots studied by Ponce. Micro-channels, as used herein, are defined as small ephemeral, first and second order channels which receive only negligable interflow and groundwater inputs.

Importance of Study

The recent emphasis on environmental quality has created a concern for not only the sources of pollution but also the mechanisms involved in pollutant release. The U.S. Environmental Protection Agency

(1971, as cited by the Utah Water Research Laboratory, 1975) estimated that 21.4 percent of the total production of salt from the Price River basin is contributed by diffuse sources. In light of the fact that Ponce (1975) attributed less than one percent of this to overland flow, a serious look at the contribution from ephemeral micro-channels is warrented. Also, a better understanding of the mechanisms of diffuse salt release will aid land managers in devising control measures.

Study Objectives

The objectives of this study are:

1. To evaluate and place in perspective the salinity contributions from micro-channels in the Price River basin, Utah;

2. To determine the channel, flow, and soil factors that influence salt pickup from this source; and

3. To develop a methodology that land managers may use to predict salt production from micro-channels in the Price River and similar basins.

STUDY AREA

General

The Price River basin (figure 1) is located in east-central Utah, approximately 100 miles (160 km) southeast of Salt Lake City. It is about 75 miles (121 km) in length with a maximum width of 32 miles (52 km) and an area of nearly 1890 square miles (4895 km^2) or 1,208,000 acres (488,900 ha). Elevation ranges from 10,433 feet (3182 m) above mean sea level (msl, Monument Peak in the Wasatch Plateau) to approximately 4200 feet (1280 m) above msl at the confluence of the Price and Green Rivers. The principal vegetation types of the basin, as defined by Shantz and Zon (1924) and Cannon (1960), are Western Pine Forest (Yellow Pine - Douglas Fir) in the headwaters area, Southwestern Coniferous Woodland (Pinyon - Juniper) on the lower slopes, and Northern Desert Shrub (Sagebrush - Shadscale) in the valley bottoms.

Although coal mining is the largest industry for commercial products, the leading employer in the basin is government, including federal, state, and local. Of the farming endeavors, livestock production is the primary activity, with sheep and beef being the dominate concern. Alfalfa and small grains are the main cash crops grown (Utah Division of Water Resources, 1975). A total of about 46,000 acres (18,600 ha), or three percent of the basin, is under irrigation (Mundorff, 1972). This irrigated acreage, according to Swenson et al. (1970), has decreased in recent years, probably due to the accumulation of salts in the soil and the shortage of irrigation water.

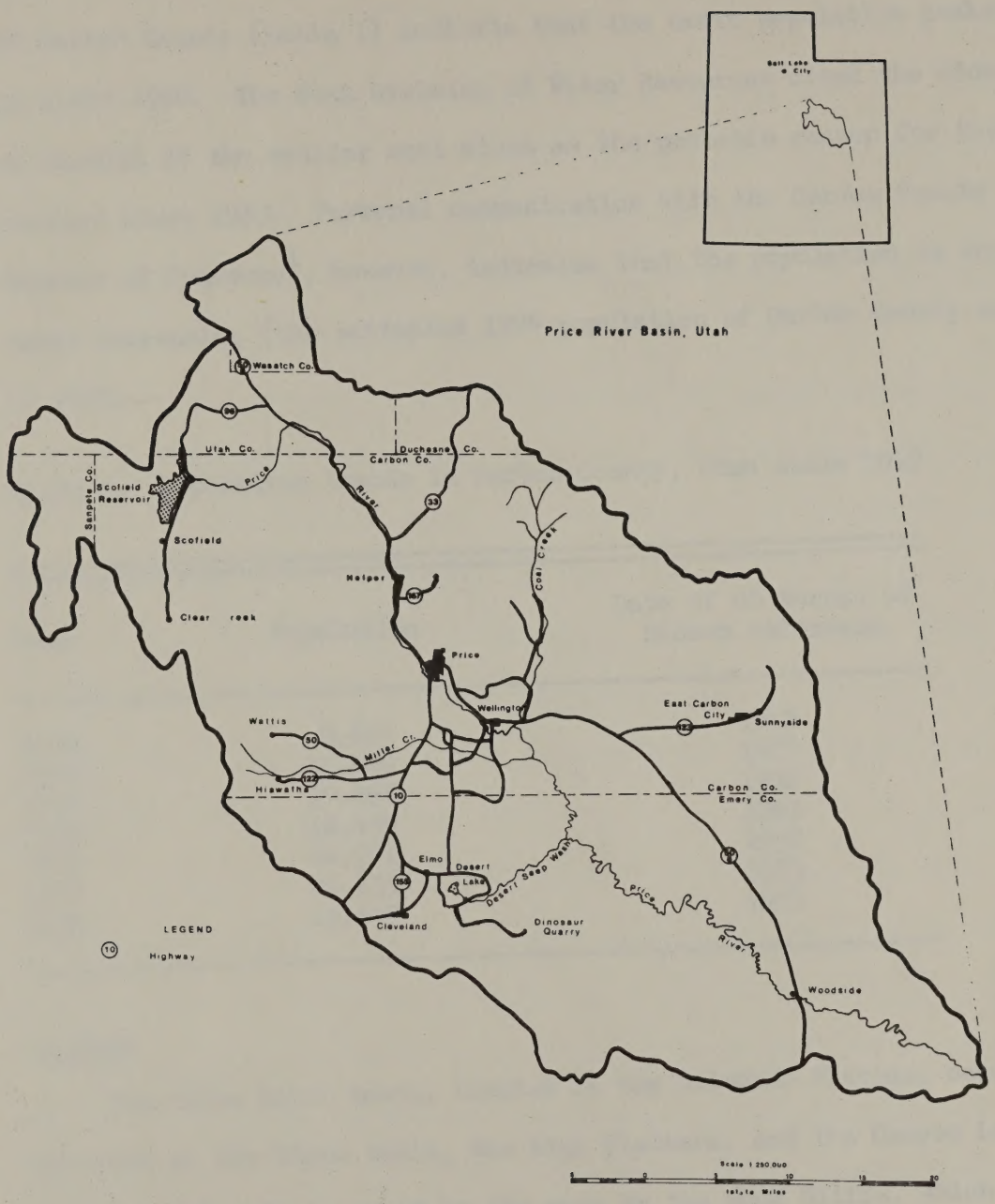


Figure 1. The Price River basin of east-central Utah (1 mile = 1.61 km)

The population of the basin is approximately equal to that of Carbon County (Utah Division of Water Resources, 1975). Census reports of Carbon County (table 1) indicate that the basin population peaked in about 1950. The Utah Division of Water Resources cited the closing of several of the smaller coal mines as the probable reason for the decline since 1950. Personal communication with the Carbon County Chamber of Commerce[1], however, indicates that the population is once again increasing (the estimated 1974 population of Carbon County was 17,700).

Table 1. Population trends in Carbon County, Utah since 1910

Year	Population	Date of US Bureau of Census reference
1910	8,624	1913
1920	15,489	1922
1930	17,798	1932
1940	18,459	1943
1950	24,901	1952
1960	21,135	1963
1970	15,647	1973

Geology

The Price River basin, located in the Colorado Plateau, occupies portions of the Uinta Basin, the High Plateaus, and the Canyon Lands (Hunt, 1956). It is bound on the east by the Book Cliffs, which consist of nearly flat-lying beds of sandstone and shale, and on the west by the Wasatch Plateau, a southward continuation of the rocks and

[1]Letter dated 7 September 1976

topography of the Book Cliffs (Lupton, 1916). Erosion has played a dominant role in the formation of these geologic structures (Stokes, 1944).

Between the Book Cliffs and the Wasatch Plateau lies the monoclinal valley of Castle Valley (Thorne et al., 1967) which owes its existence to the soft, thick Mancos shale. The only notably resistant member found within the valley, the Ferron sandstone, is hard enough to form a low ridge (Stokes, 1944).

Near the south end of Castle Valley is the kidney-shaped San Rafael Swell, an elongate anticline approximately 80 miles (130 km) long and 30 miles (48 km) wide. The eastern side of the Swell, known as the Reef, is a sawtooth ridge of sandstone with walls up to 1500 feet (455 m) high. The western side is poorly marked due to the gradual dip of the Swell as it continues into Castle Valley. The Price River crosses the San Rafael Swell near the north end and penetrates as deep as Jurasic formations (Stokes, 1944).

The major stratigraphic units present in the basin are shown in figure 2 with the percent of the basin covered by each of these units given in table 2. Of primary importance to this study are those units comprising the Mancos shale, a blueish-gray shale intermixed with thin lenses of calcareous sandstone, limestone and a few concretionary beds (Stokes and Cohenour, 1956). The Mancos shale, covering nearly 25 percent of the surface of the basin, is traditionally considered the prime source of non-point salt within the basin.

The Mancos shale was divided into three members by Stokes and Cohenour (1956). The Masuk, the youngest of the Mancos members, varies

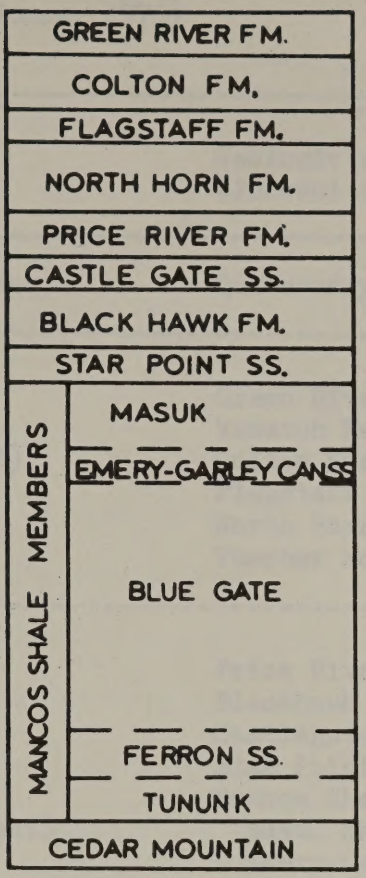


Figure 2. Major stratigraphic units present in the Price River basin (from Ponce et al., 1975)

from 1000 or 1100 feet (305 or 335 m) thick in the northern and central portions of the Wasatch Plateau to about 600 feet (185 m) thick west of Emery County.

The Bluegate, separated from the Masuk by the Emery - Garley Canyon Sandstone, ranges in thickness from 1500 to 2000 feet (455 to 610 m). It weathers to produce easily eroded, relatively unproductive soils containing large amounts of gypsum and evaporites (Thorne et al., 1967). The fossils present in the formation indicate that it is almost entirely of the Niobrara age.

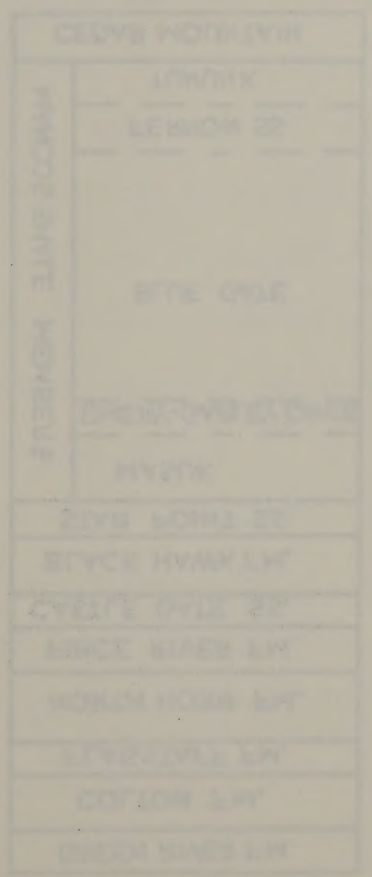


Table 2. Stratigraphic units present at the surface in the Price River basin (from Ponce, 1975)

Relative geologic time	Geologic unit (Percent basin coverage)
Quaternary (13.28 percent)	Quaternary deposits (13.28)
Tertiary (25.04 percent)	Green River Formation (8.05) Wasatch Formation (0.25) Colton Formation (3.87) Flagstaff Limestone (6.61) North Horn Formation (5.50) Tuscher Formation (0.76)
Cretaceous (48.00 percent)	Price River Formation (4.94) Blackhawk Formation (11.29) Castlegate Sandstone (2.61) Star Point Sandstone (1.72) Mancos Shale Masuk Shale Member (4.40) Emery-Garley Canyon Sandstone Member (1.04) Blue Gate Shale Member (9.29) Ferron Sandstone Member (1.04) Tununk Shale Member (1.21) Mancos Undivided (10.00) Dakota Sandstone (0.46)
Jurassic (13.68 percent)	Cedar Mountain Formation (4.83) Morrison Formation Brushy Basin Member (1.85) Salt Wash Member (2.81) Summerville Formation (0.30) Curtis Formation (0.62) Entrada Formation (0.61) Carmel Formation (2.66)

The oldest of the Mancos shale members is the Tununk, separated from the Bluegate member by the Ferron sandstone. It offers little resistance to erosion and therefore forms a lowland or slope between the harder formations. Blue-gray to black in color, the Tununk ranges in thickness from 400 to 600 feet (120 to 180 m) with fossils from the Graneros, Greenhorn, and Carlile time periods. It is the initial deposit of the late Cretaceous marine invasion which covered most of the interior of the continent. Locally the Tununk contains heavy carbonaceous deposits in the upper 100 feet (30 m). It is underlain by the Dakota sandstone (Stokes and Cohenour, 1956).

Table 2 also mentions Mancos Undivided. The data compiled by Stokes (1964) indicates that the Mancos members in that portion of the basin west of the Price River had been mapped in relative detail while those east of the river were labled merely as Mancos. Thus, Mancos Undivided consists of all members of the Mancos shale without reference to their specific location.

Available groundwater supplies within the basin are limited primarily to the headwaters area with the North Horn and Flagstaff formations containing most of the aquifers (Cordova, 1964). Because of the high sulfate and bicarbonate sodium content of the water originating in the Mancos shale (Utah Division of Water Resources, 1975) only limited use of the groundwater supply in the valley areas has been realized. Groundwater in the headwaters area is used primarily for stock watering, as a municipal supply for the cities of Price and Helper, and as a supplemental supply for Utah Power and Light's steam power plant near Helper (Cordova, 1964).

Soils

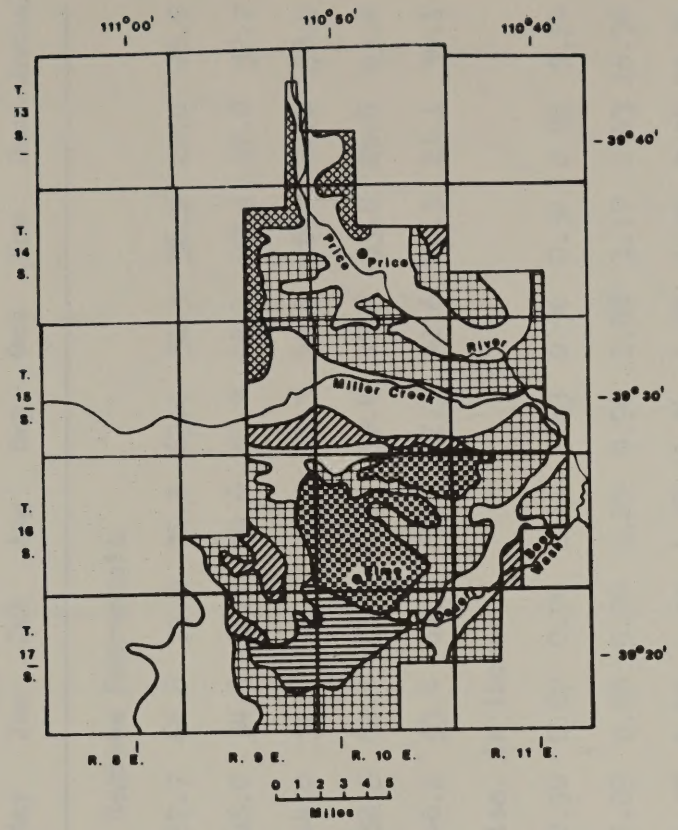
Two soil surveys of portions of the Price River basin have been published (Youngs and Jennings, 1939; Swenson et al., 1970). These surveys cover a band of agricultural and national resource land in the central part of the basin (see figure 3). A general soil map, showing the soil associations found in the northern portion of the surveyed area (Swenson et al., 1970), is given in figure 4.

Generally, the parent materials of soils found within the surveyed areas are of three main types (Swenson et al., 1970). Soils which have developed in residiuum that weathered from shale and sandstone are typically salty. These include the Chipeta, Persayo, Killpack, and Cedar Mountain soils. Parent material consisting of glacial outwash deposited during Pleistocene time is found along the western and northern edges of Castle Valley. This outwash, which has formed various gravel surfaces, is composed of calcareous sandstone and quartizite. A third group of soils present in the Price River basin are those formed in alluvium or colluvium derived from shale or glacial outwash. These soils have a moderate to high salt content and include the Saltair, Libbings, Cache, Ravola, and Billings soils.

Climate

The climate of the Price River basin is semiarid and continental. Table 3 contains mean monthly and annual temperature and precipitation data for the basin. The data presented in this table were arrived by averaging the mean monthly values for the periods of record. Figure 5 presents the data graphically for the stations at Scofield Dam and Price Game Farm, giving an indication of the expected ranges.

Figure 3. Extent of published soil surveys within the Price River basin



SOIL ASSOCIATIONS

Chipeta-Killpack association: Gently rolling and gently sloping to moderately steep, well-drained, moderately fine textured soils that are shallow and moderately deep over shale; on uplands

Ravola-Billings-Penoyer association: Nearly level to gently sloping, deep, well-drained and moderately well-drained, medium textured and moderately fine textured soils on alluvial fans and flood plains and in alluvial valleys

Saltair-Libbings association: Nearly level to gently sloping, deep and moderately deep, salty, moderately fine textured soils on bottom lands and foothills

Sanpete-Minchey association: Gently sloping, deep, well-drained, medium textured to moderately fine textured soils over gravel, on terraces, benches, and old alluvial fans

Chipeta-Persayo-Badland association: Gently sloping and gently rolling to steep, well-drained, moderately fine textured and medium textured soils that are shallow over shale and eroding shale outcrops; on uplands

Rock land-Shaly colluvial land-Castle Valley-Kenilworth association: Gently sloping to very steep, shallow to deep, gravelly and stony soils and rock land; on benches and hills

Figure 4. Soil associations in the central portion of the Price River basin (from Mundorff, 1972; 1 mile = 1.61 km)

Table 3. Mean monthly and annual temperature and precipitation for stations in the Price River basin (from the Utah Division of Water Resources, 1975)

Station	Elevation, in feet	Month												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
		Temperature, in degrees Fahrenheit												
Price Game Farm	5580	22.7	29.9	39.0	48.4	57.7	66.8	73.3	71.2	63.0	51.3	36.9	27.0	48.9
Scofield Dam	7630	13.2	16.2	25.1	36.1	46.0	54.6	61.1	59.6	52.7	42.1	27.5	17.8	37.7
Clear Creek	8300	19.4	20.7	26.2	35.2	44.0	52.1	58.7	57.7	50.5	40.7	28.4	22.8	38.0
Hiawatha	7230	23.0	26.7	33.5	43.6	52.5	62.2	69.1	66.7	59.4	47.8	33.8	26.0	45.4
Soldier Summit	7460	17.6	20.9	28.2	38.1	46.2	53.4	61.3	60.1	52.5	41.6	28.3	21.1	39.1
		Precipitation, in inches												
Price Game Farm	5580	0.73	0.65	0.66	0.61	0.70	0.67	0.90	1.11	0.83	0.96	0.54	0.88	9.24
Scofield Dam	7630	2.66	2.13	1.48	0.98	1.09	0.88	0.94	1.29	0.96	1.08	1.17	1.43	16.04
Clear Creek	8300	2.65	2.69	2.68	1.95	1.57	1.43	1.53	1.56	1.34	2.02	1.70	2.41	23.54
Hiawatha	7230	1.00	0.89	0.97	0.91	1.08	0.95	1.18	1.84	1.00	1.33	0.78	0.96	12.87
Soldier Summit	7460	1.50	1.70	1.54	1.01	1.10	0.62	1.17	1.38	1.06	1.06	1.07	1.51	14.72

Note: $^{o}C = (^{o}F-32)\ (5/9)$; 1 inch = 25.4 mm; 1 foot = 0.305 m

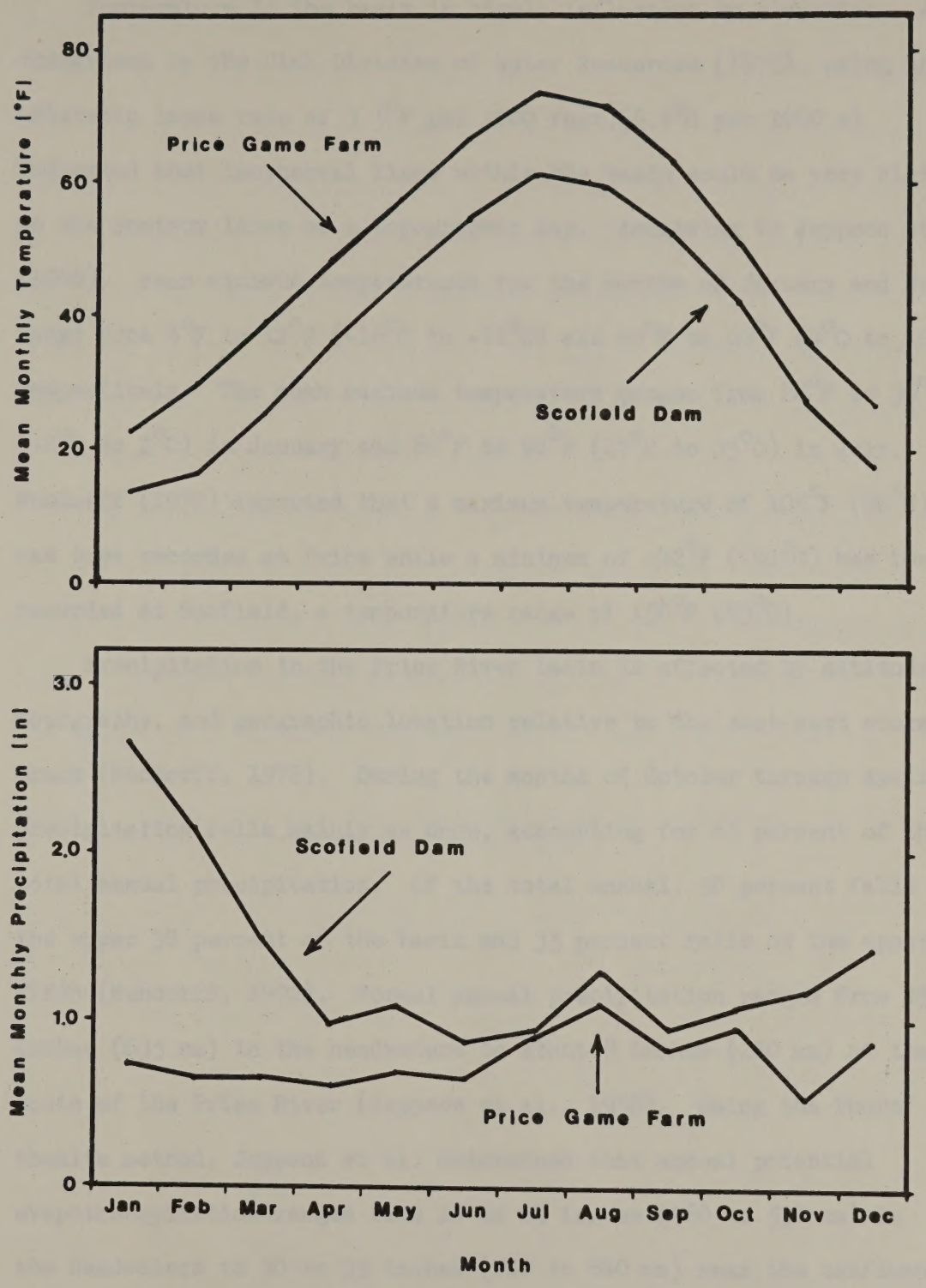
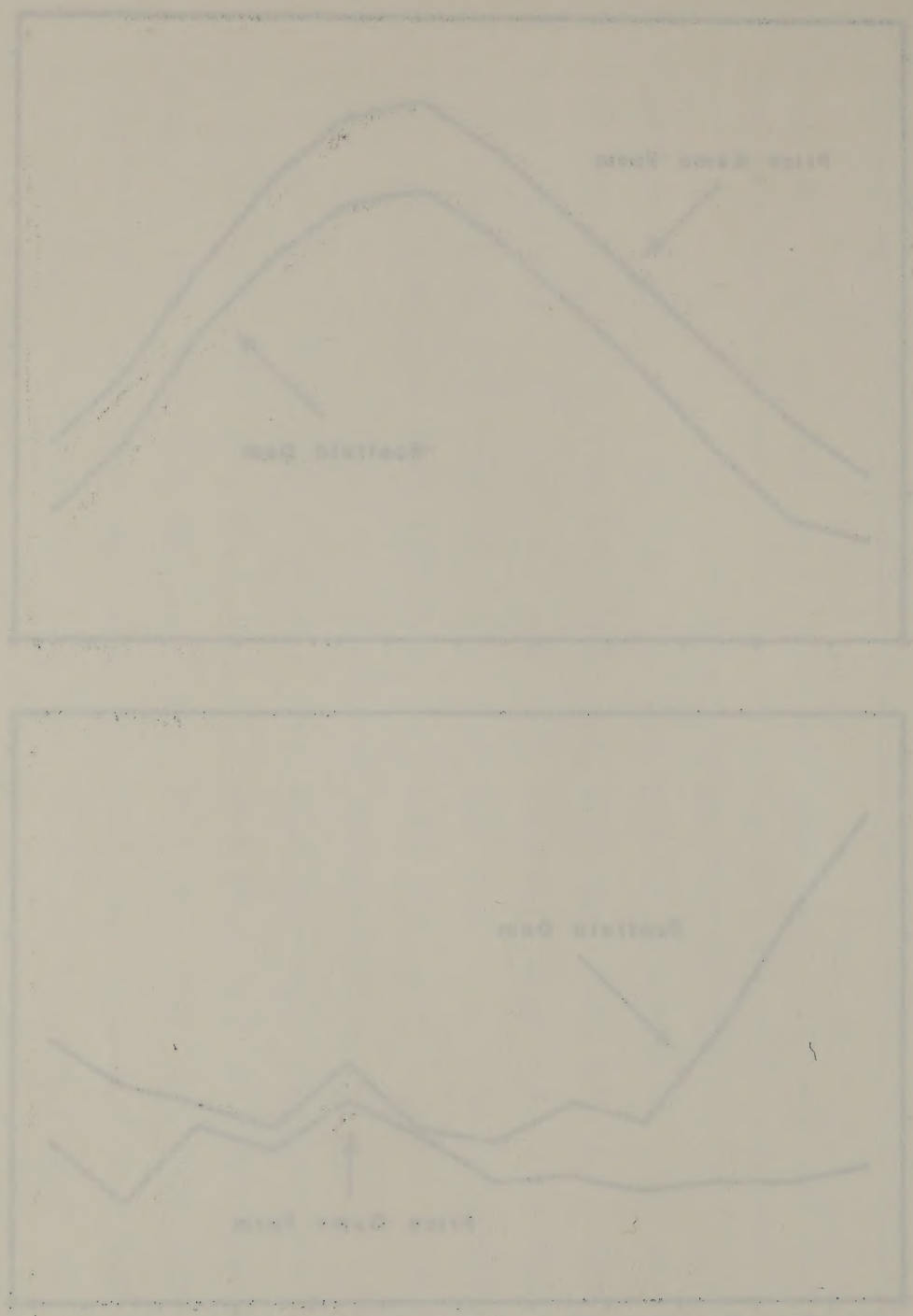


Figure 5. Mean monthly temperature and precipitation at Scofield Dam and Price Game Farm ($^{o}C = (^{o}F-32)\ (5/9)$; 1 inch = 25.4 mm)



Temperature in the basin is highly influenced by elevation. A comparison by the Utah Division of Water Resources (1975), using an adiabatic lapse rate of 3.5°F per 1000 feet (6.4°C per 1000 m) indicated that isothermal lines within the basin would be very similar to the contour lines of a topographic map. According to Jeppson et al. (1968), mean minimum temperatures for the months of January and July range from 4°F to 12°F (-16°C to -11°C) and 40°F to 60°F (4°C to 16°C), respectively. The mean maximum temperature ranges from 28°F to 36°F (-2°C to 2°C) in January and 80°F to 92°F (27°C to 33°C) in July. Mundorff (1972) reported that a maximum temperature of 108°F (42°C) has been recorded at Price while a minimum of -42°F (-41°C) has been recorded at Scofield, a temperature range of 150°F (83°C).

Precipitation in the Price River basin is affected by altitude, topography, and geographic location relative to the east-west storm track (Mundorff, 1972). During the months of October through April, precipitation falls mainly as snow, accounting for 65 percent of the total annual precipitation. Of the total annual, 50 percent falls on the upper 30 percent of the basin and 35 percent falls on the upper one-fifth (Mundorff, 1972). Normal annual precipitation ranges from 25 inches (635 mm) in the headwaters to about 8 inches (200 mm) at the mouth of the Price River (Jeppson et al., 1968). Using the Thornthwaite method, Jeppson et al. determined that annual potential evapotranspiration ranges from 18 to 21 inches (460 to 530 mm) in the headwaters to 30 to 33 inches (760 to 840 mm) near the confluence of the Price and Green Rivers.

Streamflow

As could be expected, streamflow within the basin is also highly dependant upon elevation. According to the Utah Division of Water Resources (1975) nearly two-thirds of the annual streamflow occurs in areas above the 8000 foot (2440 m) level, which occupy only 21 percent of the basin. Water yields range from 12 inches (305 mm) near Scofield Reservoir to less than one inch (25 mm) in the southern two-thirds of the watershed. Measured peak flows occur generally during the month of May as a result of snowmelt runoff.

The effects of decreased precipitation in a downstream direction and the withdrawl of water for irrigation use in the central portion of the basin is evident upon examination of selected streamflow data. Table 4 presents the long-term mean discharge at three stations within the basin, as reported by Mundorff (1972). Especially marked is the

Table 4. Long-term mean discharge at selected stations in the Price River basin (from Mundorff, 1972)

Station	Drainage Area, in square miles (square kilometers)	Discharge, in cubic feet per second (cubic meters per second)	Discharge, in cubic feet per second per square mile (cubic meters per second per square kilometer)
Scofield	155 (401)	60 (1.7)	0.387 (0.0042)
Heiner	415 (1075)	111 (3.1)	0.267 (0.0029)
Woodside	1500 (3885)	103 (2.9)	0.079 (0.0007)

decrease in discharge per unit area noted between the Heiner station (located just north of Helper) and the station at Woodside, near the mouth of the Price River. As an example of the demands of irrigation on the river, Mundorff states that on 25 September 1969 the flow at Scofield reservoir was 115 cfs (3.3 cms), 109 cfs (3.1 cms) at Heiner, and 10 cfs (0.3 cms) at Price.

LITERATURE REVIEW

Only a limited amount of research in the past has dealt with the production of salt from diffuse, wildland sources in the Price River basin. Because of the nature of this study, however, it is also of interest to review the literature dealing with gully morphology.

Gully Processes

Gullies are a relatively common land form in the arid and semiarid regions of the world. Although gullies, much like rivers, progress through a series of stages and eventually reach a period during which morphologic processes are at a temporary standstill (referred to as dynamic equilibrium by Heede, 1975a), any trigger effect could damage the cover to the extent that bare soil and runoff are greatly increased, thus increasing gully formation (Hastings, 1959). These trigger effects may be the result of external forces such as storms of exceptionally large magnitude, earthquakes, etc. or the occurrence of non-extreme events or land management acting upon various internal watershed forces (Heede, 1975b).

In a study of the Alkali Creek watershed in western Colorado, Heede (1976) found that soon after flow in ephemeral channels begins, sediment concentration and load is high. This tends to decrease with time until the easily available sediment derived from mass wasting processes within the gully has been removed. The last recession flows may even be clear. The study presumably dealt with snowmelt runoff phenomena (dates given were in April and May) and a time duration of flow on the order of four to six weeks.

Leopold and Miller (1956) classified gullies as discontinuous or continuous. Discontinuous gullies are characterized by an abrupt headcut with a rapidly decreasing downstream depth. A fan normally develops at the lower end. The gullies generally occur in groups irregularly along the length of the drainageway. Continuous gullies, on the other hand, begin with many fingerlike extensions into the headwaters area, continuing downstream to form stream nets or systems. In this case, gully depth remains relatively constant through long reaches as a result of the channel bed gradient becoming nearly parallel to the original valley floor.

Discontinuous gullies may occur singly or in a system of chains in which one follows the next downslope. They may be incorporated into a continuous system either by fusion with tributary gullies or by becoming tributary to a continuous stream net themselves. Heede (1967) cited an example of such a fusion in the Front Range of Colorado. Within five storms of less than exceptional magnitude, the headcut of a downstream gully was observed to advance 41.6 feet (12.7 m) to the next uphill channel. The process resulted in the removal of approximately 2480 cubic feet (70 m^3) of material and the formation of one gully where there had been two.

According to Schumm and Hadley (1957) and Heede (1976), discontinuous gullies tend to begin formation at locations on mountain slopes and valley fills that are characterized by a break in slope gradient. Patton and Schumm (1975) stated that these breaks constitute a typical oversteepening of the valley floor. This oversteepening most often results from the deposition of alluvial material on the

valley slope by tributary streams. In their study of the oil-shale bearing mountains of western Colorado, Patton and Schumm further found a highly significant relationship between slope gradient, drainage area, and gully formation in areas larger than four square miles (10 km^2). Discontinuous gullies were seen to occur only above a critical slope value for a given area.

The collapse of piped soils may also be important in the formation of discontinuous gullies (Hamilton, 1970; Leopold et al., 1964). Because soil piping may be related to soil sodium, Heede (1971) demonstrated that soil chemistry must also be regarded as a factor in gully formation. Piping soils on the Alkali Creek watershed were found to have a significantly higher exchangeable sodium percentage than non-piping soils. Other factors relating to the occurrence of pipes included the presence of gullies in the area, low gypsum content in the soil, fine textured soils high in montmorillonite clay, and a sufficient hydraulic head.

Various authors have recognized the relationship between gully formation and size fraction distribution of the respective soils. Miller et al. (1962), as cited by Heede (1976), found that annual sediment production from gullies in the loess hills of Mississippi increased with an increase in the percent of uncemented sand found in the vertical gully walls. In a regression analysis of numerous western channels, Schumm (1960) noticed than an increase in the width-depth ratio of gullies conformed with a decrease in the average percent silt and clay (or an increase in the average percent sand) in the channel bank and bottom material.

Gully morphology and growth are also influenced by bank vegetation. Studies in Vermont (Zimmerman et al., 1967) and southern California (Orme and Baily, 1970) indicate that the encroachment by vegetation on ephemeral channels may have a stronger influence on channel formation than soil type in many cases.

Numerous equations have been developed to predict gully growth. Seginer (1966), upon studying various gullies in Israel, derived the statistical growth model

$$E = cA^{\frac{1}{2}} \qquad (1)$$

in which E = the advancement rate of the gully headcut, in meters per year; A = the watershed area draining into the headcut, in square kilometers; and c = a constant that varies from area to area. Thompson (1964) studied a number of variables which are presumably related to headcut advancement and developed the equation

$$R = 0.15\ (A^{0.49})\ (S^{0.14})\ (P^{0.74})\ (E^{1.00}) \qquad (2)$$

in which R = the gully head advancement, in feet, over a time period equal to that represented in the rainfall variable, P; A = the drainage area above the gully head, in acres; S = the slope of the approach channel above the gully head, in percent; P = the summation of rainfall, in inches, from 24 hour storms equal to or greater than 0.05 inches in magnitude; and E = the approximate clay content (size fraction less than 0.005 mm in diameter) of the soil, in percent. An analysis of this regression equation gave an R^2 value of 0.77

while the results of a t-test of each of the independant variables showed that all but the slope factor, S, were significant contributors to the equation at the 5 percent level. In a similar regression test, Beer and Johnson (1963) found that gullying processes are best described by a logarithmic model.

Although statistical investigations have shed light on the important variables in gully growth, Heede (1976) maintains that quantification and prediction of gully growth still lack precision because past rates do not necessarily indicate future rates. This problem, he claims, can be somewhat alleviated by taking the stage of gully development into account. The simplified approach, he further states, at best presents an empirical relationship valid for a given drainage area at a given point in time.

Price River Basin Diffuse Source Salinity

Recent research by Blackman et al. (1973) has indicated that the Price River basin is one of the prime sources of the salinity pollution of the Colorado River. It was found that although the basin contributed only 0.7 percent of the average daily flow at Lake Powell from 1965 to 1966, it supplied 3.4 percent of the total dissolved solid load. Of the 90 sampling points surveyed in the Colorado River basin above Lake Powell, the ratio of percent salt load to percent flow was higher from the Price River basin than anywhere else.

Following a more detailed survey of the basin, Mundorff (1972) reported that although the surface water in the headwaters area is

of relatively good quality, a rapid deterioration occurs as the Price River crosses the Mancos shale. From the headwaters to the junction with Spring Canyon Creek, the Price River has a total dissolved solids content normally less than 400 mg/l, predominately of a calcium bicarbonate type[2]. From this point downstream, the river crosses various Mancos members. At Wellington, near the center of the basin, the average salt concentration ranges from 600 to 2400 mg/l, being variable mixed type in nature. At Woodside, near the confluence of the Price and Green Rivers, the average total dissolved solids concentration over a period of 18 years (1952 to 1969) has varied between 2000 and 4000 mg/l. The type has been predominantly sodium sulfate. Mundorff attributed this deterioration in water quality to the drainage of the Mancos shale, depletions in flow for irrigation which act to concentrate the salt load, and the discharge of sewage and irrigation return flows into the river during periods of low flow. Mundorff also found that increases in total dissolved solids concentrations are probably typical of the southward-flowing tributaries which head in the Book Cliffs and flow across Mancos derived soils.

Ponce (1975) studied the effects of overland flow on salt production from diffuse sources within the basin using an infiltrometer technique. In studying the contributions from soils derived from the major geologic types, he noted that the Undivided Mancos

---

[2]For concentrations up to approximately 7000 milligrams per liter (mg/l), parts per million (ppm) equals mg/l.

and the Bluegate member of the Mancos shale (particularly the lower two-thirds of this member) are considered to be the major contributors of salinity to overland flow. It was also found that salt concentrations are highest as surface runoff begins (during the first 13 to 18 minutes). This initial surge is followed by a period of relatively constant salinity concentration. A comparison of the salt concentrations of overland flow water and Price River water lead to the conclusion that the former is low in relation to the latter. While the Price River at Woodside has an average total dissolved solids concentration of 2000 to 4000 mg/l (Mundorff, 1972), the most saline Mancos site yielded only 858 mg/l salt.

Natural field variability was found to be directly related to the salinity of the surface runoff. The greatest variation within and between sites, according to Ponce, was associated with runoff occurring over the salt-bearing Mancos shale soils. This phenomenon made it difficult to determine the various factors affecting non-point salt loading from overland flow.

Regardless of this natural variability, a study undertaken to determine the soil factors affecting salt production from overland flow showed that the one-to-one soil-to-water extract correlated better with the salinity of the surface runoff than did the saturation extract. Ponce found that the electrical conductivity (EC) of the one-to-one extract of the surface crust (0-0.1 inch or 0-2.5 mm) was highly correlated with the EC of the surface runoff whereas that of the surface inch (2.5 cm) was not. This suggested that salt production from overland flow is the result of interaction with a very thin surface layer.

Ponce determined that salt concentrations tend to vary directly with the suspended sediment concentrations of the surface runoff. The explanation given was that when soil particles become detached, the amount of surface area exposed to runoff water is greatly increased. This also exposes more soil and salts and the process continues. In connection with this, two rainfall intensity related mechanisms of salt release were discovered. When a change in intensity was not accompanied by a direct change in the erosion rate, salinity concentrations varied inversely with rainfall intensity, suggesting the occurrence of a dilution process. When an increase in intensity was accompanied by an increase in suspended sediment, the salt concentration varied directly with the intensity, indicating a "digging" action by the rainfall, exposing more soil and salt to the runoff water. The two processes were also seen to act simultaneously in some cases.

A regression analysis by Ponce resulted in the following equation for predicting salinity from overland flow in the Price River basin:

$$TDS_c = B_o + B_1P + B_2Q \qquad (3)$$

in which TDS_c = the corrected total dissolved solids concentration (TDS of the runoff minus TDS of the rainfall), in mg/l; P = the rainfall rate, in inches per hour; Q = the runoff rate in inches per hour; and B_o, B_1, and B_2 = site specific regression coefficients which incorporate the necessary unit conversions. The equation was found to explain 46 percent of the variation for all plots studied. Utilizing this equation, Ponce estimated that the contribution of

salinity to the Price River from overland flow on Mancos shale lands amounts to less than one percent of the total salt measured at Woodside.

In an effort to better define the mechanisms involved in non-point salt production in the Price River basin, Whitmore (1976) undertook a set of controlled laboratory experiments with Mancos derived soils. The salinity of Mancos soils was attributed to the presence of gypsum and indigenous evaporite salts. Lithium was found to be the dominate monovalent cation in about half of the samples analyzed.

According to Whitmore, salt release from Mancos derived soils is controlled by the parabolic diffusion law which states that

$$C = K' (t)^{\frac{1}{2}} \qquad (4)$$

in which C = the concentration of the diffusing material at time t and K' = the overall diffusion constant. Two diffusion controlled salt release processes were recognized by Whitmore. The first, a fast reaction, accounts for approximately 80 to 90 percent of the total salt production and is due to the presence of the fine mineral fraction and precipitated salts on the surface of mineral particles. This process was seen to have a duration of about two minutes under the controlled conditions of the experiment. The second reaction, accounting for 10 to 20 percent of the total salt production and lasting upwards from seven to nine days, is the result of the dissolution of the larger, more resistant mineral fraction. A column test showed that a given Mancos derived soil was capable of producing 1.89 percent of its weight in salt.

METHODS

Site Selection

Eight sites within the Price River basin were chosen for investigation (figure 6) with the number of channels selected at each site varying from one to three (see Appendix A for a description of each site and channel chosen). The selection of sites and channels was based upon the following criteria:

1. Be accessible by road;
2. Be on land managed by the BLM;
3. Be somewhat obscure from public view;
4. Be in the general vicinity of the overland flow plots studied by Ponce (1975) and/or the channel process study sites currently under investigation;[3]
5. Contain channel sections at least 100 feet (30 m) in length and typical of the general area; and
6. Have channel sections conducive to instrumentation installation.

Because of the limited extent of organized soil surveys of the area (see figure 3), the selection of sites was based upon geologic type, as shown in table 5. Geologic maps prepared by Stokes (1964) were used in the selection process. Sites 1 through 7 where chosen to determine the contribution of each of the shale members of the Mancos shale to total salt production. Sites 1, 5, and 6 were

---

[3]The channel process study is a project funded by the U.S. Bureau of Reclamation and contracted to Utah State University. Its purpose is to investigate the production of salt from the larger intermittent and perennial channels of the Price River basin.

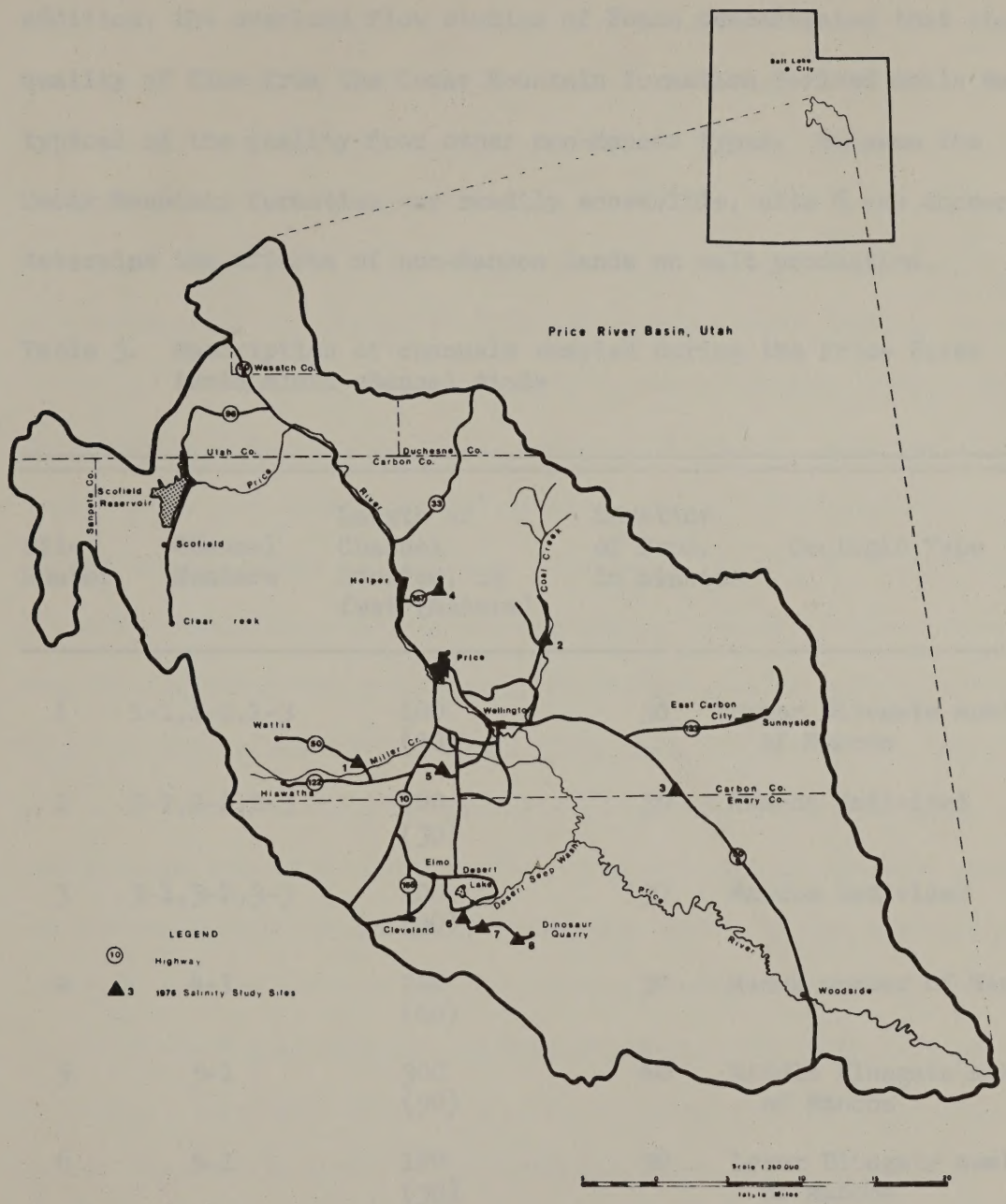


Figure 6. Micro-channel study site locations within the Price River basin (1 mile = 1.61 km)

chosen using the arbitrary delineation of Ponce (1975) to determine the variability within the Bluegate member of the Mancos shale. In addition, the overland flow studies of Ponce demonstrated that the quality of flow from the Cedar Mountain formation derived soils was typical of the quality from other non-Mancos types. Because the Cedar Mountain formation was readily accessible, site 8 was chosen to determine the effects of non-Mancos lands on salt production.

Table 5. Description of channels sampled during the Price River basin micro-channel study

Site Number	Channel Numbers	Length of Channel Studied, in feet (meters)	Duration of Runs, in minutes	Geologic Type
1	1-1,1-2,1-3	100 (30)	30	Upper Bluegate member of Mancos
2	2-1,2-2,2-3	100 (30)	30	Mancos Undivided
3	3-1,3-2,3-3	100 (30)	30	Mancos Undivided
4	4-1	200 (60)	30	Masuk member of Mancos
5	5-1	300 (90)	60	Middle Bluegate member of Mancos
6	6-1	100 (30)	30	Lower Bluegate member of Mancos
7	7-1	100 (30)	50	Tununk member of Mancos
8	8-1	100 (30)	30	Cedar Mountain formation

Hydrology and Water Quality

Because natural rainfall in the area is sporadic and artificial input via rainfall simulation sprinklers would have required enormous amounts of water, the production of salt was investigated by releasing water, which had been trucked to each site, directly into the study channels. This water was taken from a local culinary supply and had a conductivity in the range of 350 to 400 μmhos/cm at 25°C, which is not atypical of the runoff quality measured by Ponce (1975).

One foot HS flumes (Agricultural Research Service, 1962), equipped with Stevens Type F water level recorders, Model 61, were installed at both the up- and downstream end of each channel test section with the exception of channel number three at sites 1, 2, and 3. This type of streamflow measuring combination was chosen because 1) the flumes and water level recorders were already fabricated and/or available and 2) they accurately measure low flows (less than 0.8 cfs or 0.2 cms).[4] The upstream flume was modified slightly to include a box and baffle into and through which the water flowed. The box insured that the water did not come into contact with the channel prior to the beginning of the test section and the baffle eliminated undue turbulence, thus allowing for a more accurate head measurement. In order to avoid excessive, unnatural erosion, a three sided galvanized metal box was placed beneath the mouth of the upstream flume.

Figure 7 shows the general layout of site 1 which was also typical of sites 2 and 3. The layout of the other sites was modified

---

[4]The Stevens Type F, Model 61 water level recorder accurately responds to a change in head of 0.01 foot (0.003 m). HS flumes are specifically designed to measure runoff from areas where the maximum flow rate is not expected to exceed the indicated values.

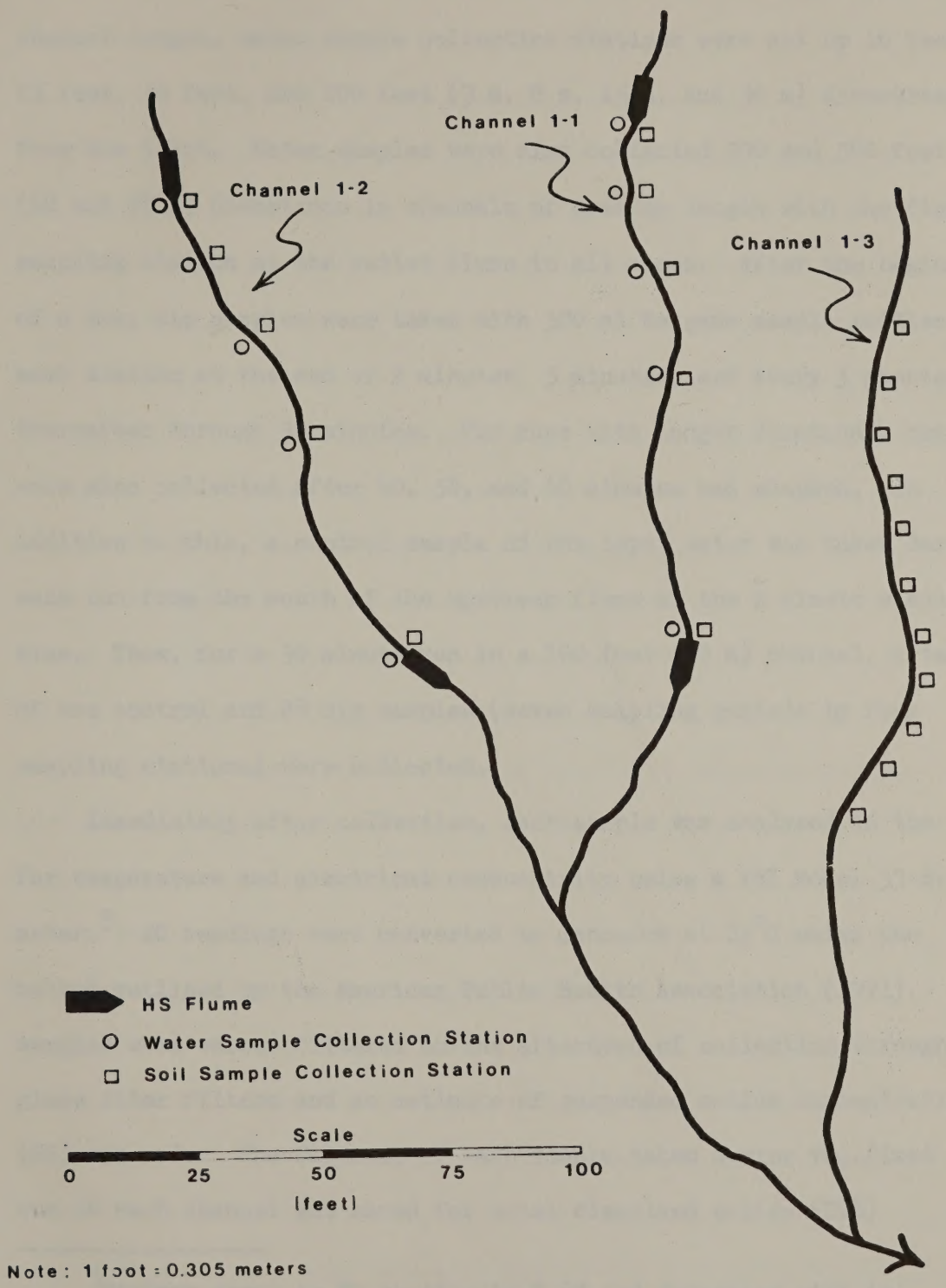


Figure 7. Field layout of micro-channel study site number one

slightly according to the length and number of channels as indicated in table 5. In order to determine salt production as a function of channel length, water sample collection stations were set up 10 feet, 25 feet, 50 feet, and 100 feet (3 m, 8 m, 15 m, and 30 m) downstream from the inlet. Water samples were also collected 200 and 300 feet (60 and 90 m) downstream in channels of greater length with the final sampling station at the outlet flume in all cases. After the beginning of a run, dip samples were taken with 500 ml Nalgene sample bottles at each station at the end of 2 minutes, 5 minutes, and every 5 minutes thereafter through 30 minutes. For runs with longer durations, samples were also collected after 40, 50, and 60 minutes had elapsed. In addition to this, a control sample of the input water was taken during each run from the mouth of the upstream flume at the 2 minute sampling time. Thus, for a 30 minute run in a 100 foot (30 m) channel, a total of one control and 28 dip samples (seven sampling periods by four sampling stations) were collected.

Immediately after collection, each sample was analyzed in the field for temperature and electrical conductivity using a YSI Model 33 S-C-T meter.[5] EC readings were converted to μmhos/cm at 25°C using the method outlined by the American Public Health Association (1971). All samples were vaccum filtered on the afternoon of collection through glass fiber filters and an estimate of suspended solids concentration (SS) was made. The filtrate of each sample taken during the first run in each channel was saved for total dissolved solids (TDS)

---

[5]Maximum error in EC reading is ± 6% and decreases with increasing conductivity. Maximum error in temperature reading is 1.0°C when the temperature is 40°C. Error decreases with decreasing temperature.

determination. Relationships between TDS and EC as well as TDS and SS were developed using the data from run number one and these relationships were used to calculate TDS for subsequent runs.

In addition to the analyses mentioned above, the filtrate of the control samples plus that of samples taken from the 100 foot (30 m) station at the end of 5, 15, and 25 minutes during each run were saved for chemical analyses. Where applicable, the filtrate of samples taken from the 200 and 300 foot (60 and 90 m) stations after 40 and 60 minutes were also saved for chemical analyses. Samples were analyzed for bicarbonate, carbonate, sulfate, chloride, calcium, magnesium, sodium, potassium, and lithium ion concentrations as well as pH (also a field determination). Chemical analyses were contracted out to the Department of Soil Science and Biometeorology at Utah State University. A list of methods used for all analyses can be found in Appendix B. See table 6 for a review of the analyses performed on each sample collected.

In order to obtain an estimate of the total sediment load resulting from each run, a bucket was placed under the mouth of the downstream flume to trap the bedload passing through the flume. The bedload which dropped in the flume as a result of decreased flow velocity was scooped into additional buckets. When a significant quantity of bedload was produced, samples were saved from the channel, air dried, and weighed. Size fraction analyses by the hydrometer method of representative bedload samples were contracted out to the Department of Soil Science and Biometeorology at Utah State University.

Various methods were used to quantify the factors influencing salt pickup as a result of a given run. Prior to each run, soil samples

Table 6. Analyses completed on water samples collected during the micro-channel study

Distance Downstream, in feet (meters)	2	5	10	15	20	25	30	40	50	60
0 (Control)	C									
10 (3)	S	S	S	S	S	S	S	S	S	S
25 (7.5)	S	S	S	S	S	S	S	S	S	S
50 (15)	S	S	S	S	S	S	S	S	S	S
100 (30)	S	C	S	C	S	C	S	C	S	C
200 (60)	S	C	S	C	S	C	S	C	S	C
300 (90)	S	C	S	C	S	C	S	C	S	C

S = sample analyzed for temperature, EC, SS, and TDS.

C = sample analyzed for above items plus HCO_3^-, CO_3^{2-}, SO_4^{2-}, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, Li^+, and pH.

were taken of the surface inch of the channel bottom at locations corresponding to the water sample collection stations (see figure 7). Because of the ease of preparation and general reliability as an index of salt production (Ponce, 1975), one-to-one extracts were made of all soil samples collected from channels at sites 1, 2, and 3 prior to run number one and composites of all other samples for a given channel and run. These extracts were analyzed by the Department of Soil Science

and Biometerology at Utah State University for the physical and chemical parameters previously mentioned. All extracts were prepared in accordance with Bower and Wilcox (1965) after an initial sieving through a No. 10 sieve (0.078 inch or 1.981 mm openings). In addition, mechanical analyses, by the hydrometer method, were carried out on selected pre-run samples.

In addition to the soil samples collected from each channel, the slope of the channel was measured prior to each run using an engineer's level. In order to determine the cross sectional area of the flow, the wetted perimeter, the hydraulic radius, and the drop in the level of the channel bottom due to the run, post-run measurements were taken at small metal stakes (1/8 inch or 3.2 mm in diameter) which were driven into the channel bottom at a marked depth and at equal intervals before each run. Appendix C gives the measurements taken and the formulas used to compute the parameters mentioned.

The effect of flow rate on salt production was also to be determined. Flow rates remained relatively constant for a single run but were varied between runs over a range of approximately 0.05 to 0.20 cfs (0.001 to 0.006 cms). The time duration per run of 30 to 60 minutes and the flow rates studied were presumed to be typical of the flows which would result from the short duration, high intensity storms which prevail during the summer months in the Price River basin (Ponce, 1975). In order to determine the storm frequency necessary to produce each flow, the watershed area of each channel above the mouth of the upstream flume was surveyed using stadia methods. Area calculations were based on the coordinate method as outlined by Davis (1950).

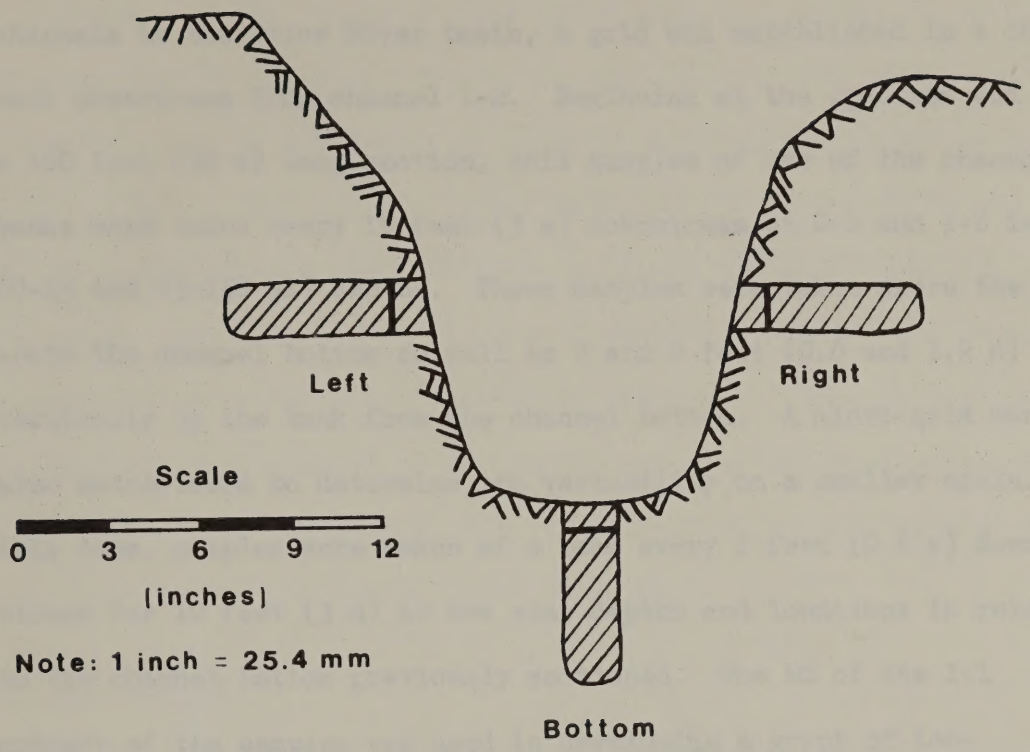


Figure 8. Soil sample locations for channel homogeneity test (looking downstream)

Natural Variability

The third channel mentioned at sites 1 through 3 (see table 5 and figure 7) was used to determine the homogeneity of the channels in the area. Beginning at the upstream end of a 100 foot (30 m) long test section, soil samples were collected every 10 feet (3 m) from the channel bottom and approximately six inches (150 mm) up each bank at depths of 0-1 inch (0-25 mm) and 1-6 inches (25-150 mm, see figure 8), for a total of 66 samples from each channel. As a measure of homogeneity, t-tests of all possible combinations within a channel were run on the EC of the one-to-one extract of each

sample, testing for the equality of means.

As another test of the natural variability present in micro-channels in the Price River basin, a grid was established in a channel bank downstream from channel 1-2. Beginning at the upstream end of a 100 foot (30 m) long section, soil samples of one of the channel banks were taken every 10 feet (3 m) downstream at 0-1 and 1-6 inch (0-25 and 25-150 mm) depths. These samples were taken where the bank meets the channel bottom as well as 2 and 4 feet (0.6 and 1.2 m) vertically up the bank from the channel bottom. A micro-grid was also established to determine the variability on a smaller scale. In this case, samples were taken of a bank every 2 feet (0.6 m) down-stream for 10 feet (3 m) at the same depths and locations in relation to the channel bottom previously mentioned. The EC of the 1:1 extract of the samples was used in developing a graph of iso-conductivity lines.

RESULTS AND DISCUSSION

Because of the amount of data collected, the results of this study and a discussion of these results has been divided into three categories. A determination of the degree of natural variability present in micro-channel systems of the Price River basin will be presented first. This will be followed by a brief discussion of the hydrologic aspects of the study. Finally, a presentation of various water quality related results will be given and discussed in detail. A complete listing of all raw data not included in the Appendices of this report will be on file in the Watershed Science Unit (Department of Range Science) at Utah State University for all interested users.

Natural Variability

In order to determine the amount of natural variability present in the system being studied, soil samples were taken from selected channels and analyzed, as previously discussed. The results of 1:1 extract EC measurements of samples collected from channel 1-3 are presented graphically in figure 9. Similar results were obtained from channels 2-3 and 3-3 as can be seen in Appendix D, where a complete listing of the data is given. These data are summarized in table 7. "Bottom" refers to the channel bottom while "Right" and "Left" refer to the right and left hand channel bank, respectively, when facing downstream.

The degree of variability within each of the three channels listed was determined using the t-test. Values for Student's t were computed using the formula

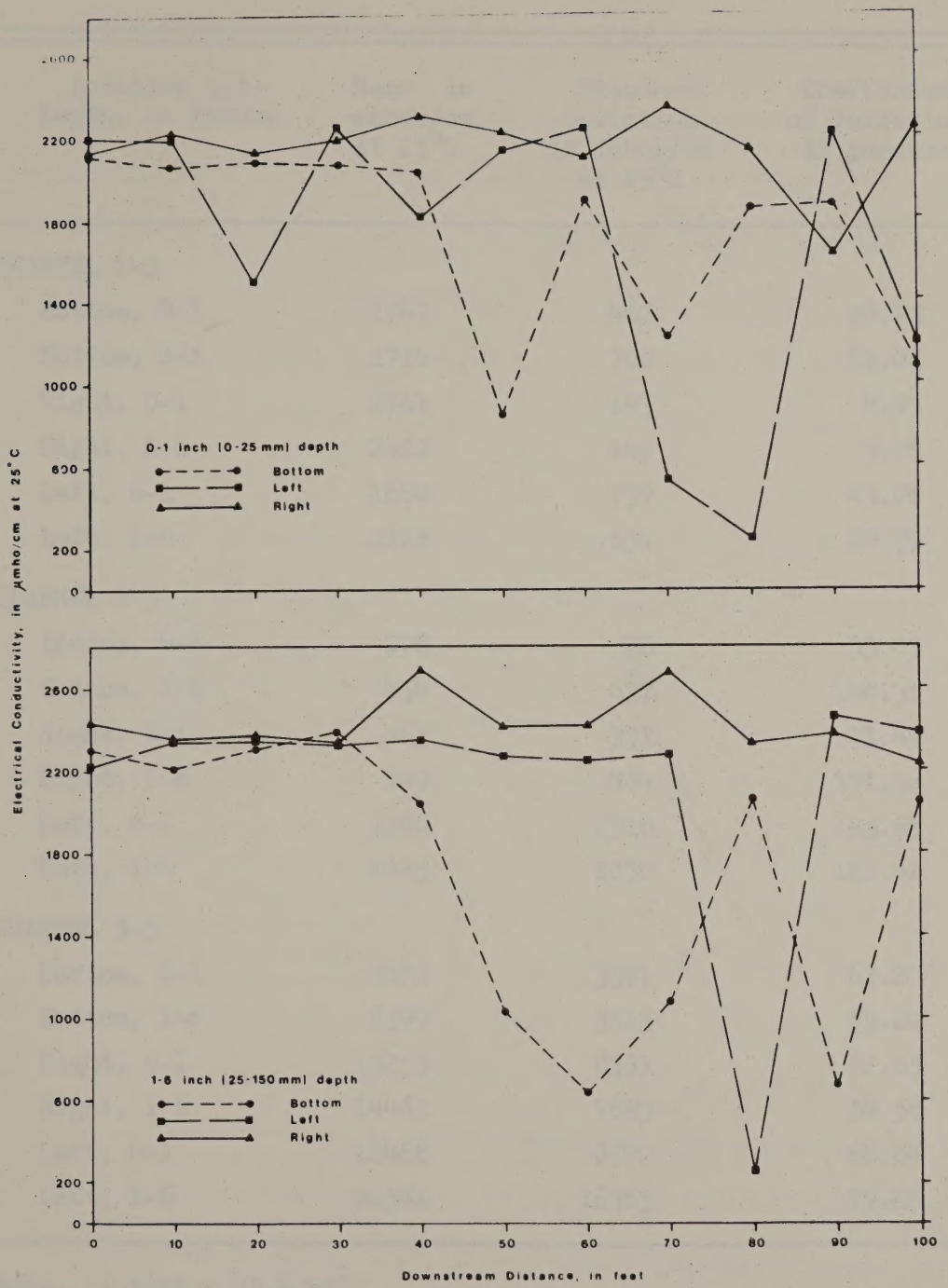


Figure 9. Electrical conductivity of one-to-one soil extracts versus downstream distance for channel 1-3 at the 0 to 1 inch (0-25 mm) and 1 to 6 inch (25-150 mm) depths

Table 7. Means and standard deviations of EC measurements from 1:1 soil extracts of samples taken from channels 1-3, 2-3, 3-3 (channel homogeneity test)

Location and Depth, in inches	Mean, in µmhos/cm at 25°C	Standard Deviation, in µmhos/cm at 25°C	Coefficient of Variation, in percent
CHANNEL 1-3			
Bottom, 0-1	1747	462	26.45
Bottom, 1-6	1710	702	41.05
Right, 0-1	2161	193	8.93
Right, 1-6	2422	140	5.78
Left, 0-1	1684	737	43.76
Left, 1-6	2128	634	29.79
CHANNEL 2-3			
Bottom, 0-1	278	92	33.09
Bottom, 1-6	454	637	140.31
Right, 0-1	463	331	71.49
Right, 1-6	749	984	131.38
Left, 0-1	1190	2328	195.63
Left, 1-6	1495	1830	122.41
CHANNEL 3-3			
Bottom, 0-1	5676	3591	63.27
Bottom, 1-6	6599	3513	53.24
Right, 0-1	13255	8331	62.85
Right, 1-6	14461	7893	54.58
Left, 0-1	12488	8597	68.84
Left, 1-6	20541	16363	79.66

Note: 1 inch = 25.4 mm

$$t = \frac{\left(\frac{|\Sigma d|}{n}\right)\left(n - 1\right)}{\left[\frac{\Sigma d^2}{n} - \left(\frac{\Sigma d}{n}\right)^2\right]^{\frac{1}{2}}} \quad ; \quad H_o: \mu_1 = \mu_2 \qquad (5)$$

in which d = the difference between each EC data pair of the particular comparison; n = the total number of data pairs; H_o = the null hypothesis tested; and μ_1 and μ_2 are the population means of the first and second data sets, respectively. Computed t-values were compared with the tabular values found in Dunn and Clark (1974) to determine the level of significance of the test. The results of the t-tests are given in table 8.

An examination of figure 9 and tables 7 and 8 reveals two important items. First, within each channel there is a great deal of variability and second, this variability tends to increase as the salt content of the channel increases. In more than two-thirds of the combinations tested, a significant difference existed between means at the 0.95 level or higher (i.e. the null hypothesis was rejected). No combination failed to reject the null hypothesis in all three channels. This high degree of spatial variability made the choice of pre-run soil sample locations in other channels difficult. The fact that these stations corresponded with the water sample collection stations (figure 7) was, therefore, merely out of convenience.

To illustrate the fact that the degree of variability increases with an increase in salinity of the system (a phenomenon also observed by Ponce, 1975), note that all but two of the comparisons for which there was no significant difference between the means at the 0.95 level or higher occurred in channel 2-3. Table 7 indicates that the

Table 8. Results of t-tests for comparisons of one-to-one soil extract electrical conductivities of samples taken from various locations within channels 1-3, 2-3, and 3-3.

Comparison	t value	df	Level of Significance
CHANNEL 1-3			
Bottom 0-1 vs. Bottom 1-6	3.092	10	*
Right 0-1 vs. Right 1-6	4.735	10	**
Left 0-1 vs. Left 1-6	2.556	10	*
All 0-1 vs. All 1-6	5.027	32	**
Bottom 0-1 vs. Right 0-1	3.004	10	*
Bottom 0-1 vs. Left 0-1	3.325	10	**
Left 0-1 vs. Right 0-1	3.010	10	*
Bottom 1-6 vs. Right 1-6	3.222	10	**
Bottom 1-6 vs. Left 1-6	3.415	10	**
Left 1-6 vs. Right 1-6	1.833	10	NS
Bottom 0-1 vs. Right 1-6	4.623	10	**
Bottom 0-1 vs. Left 1-6	4.040	10	**
Right 0-1 vs. Bottom 1-6	3.199	10	**
Right 0-1 vs. Left 1-6	1.926	10	NS
Left 0-1 vs. Bottom 1-6	4.038	10	**
Left 0-1 vs. Right 1-6	3.175	10	**
CHANNEL 2-3			
Bottom 0-1 vs. Bottom 1-6	1.451	10	NS
Right 0-1 vs. Right 1-6	2.823	10	*
Left 0-1 vs. Left 1-6	2.010	10	NS
All 0-1 vs. All 1-6	2.847	32	**
Bottom 0-1 vs. Right 0-1	2.036	10	NS
Bottom 0-1 vs. Left 0-1	2.290	10	*
Left 0-1 vs. Right 0-1	2.304	10	*
Bottom 1-6 vs. Right 1-6	2.017	10	NS
Bottom 1-6 vs. Left 1-6	2.112	10	NS
Left 1-6 vs. Right 1-6	2.285	10	*
Bottom 0-1 vs. Right 1-6	2.169	10	NS
Bottom 0-1 vs. Left 1-6	2.108	10	NS
Right 0-1 vs. Bottom 1-6	1.989	10	NS
Right 0-1 vs. Left 1-6	2.060	10	NS
Left 0-1 vs. Bottom 1-6	2.290	10	*
Left 0-1 vs. Right 1-6	2.805	10	*
CHANNEL 3-3			
Bottom 0-1 vs. Bottom 1-6	3.609	10	**
Right 0-1 vs. Right 1-6	4.719	10	**
Left 0-1 vs. Left 1-6	3.371	10	**
All 0-1 vs. All 1-6	4.924	32	**
Bottom 0-1 vs. Right 0-1	4.142	10	**
Bottom 0-1 vs. Left 0-1	3.091	10	*
Left 0-1 vs. Right 0-1	4.608	10	**
Bottom 1-6 vs. Right 1-6	3.961	10	**
Bottom 1-6 vs. Left 1-6	3.185	10	**
Left 1-6 vs. Right 1-6	5.015	10	**
Bottom 0-1 vs. Right 1-6	4.427	10	**
Bottom 0-1 vs. Left 1-6	3.203	10	**
Right 0-1 vs. Bottom 1-6	4.315	10	**
Right 0-1 vs. Left 1-6	4.060	10	**
Left 0-1 vs. Bottom 1-6	3.518	10	**
Left Left 0-1 vs. Right 1-6	6.930	10	**

NS - No significant difference between sample means at 0.95 level
* - Significantly different at 0.95 level
** - Significantly different at 0.99 level

extracts of samples taken from this channel also had the lowest mean electrical conductivity of the three channels studied. On the other hand, means of combinations within channel 3-3, where the highest salt contents were measured, were all significantly different at the 0.99 level, with one exception. Thus, as the mean EC increases, so does the calculated t value and therefore the variability.

As mentioned previously, two conductivity grids were established in a channel bank below site one. The results, presented in figure 10, enable one to visualize the salinity of the material available for mass wasting as well as the variability of the system being investigated. From the figure it is clear that both the concentration and variability of salts in channel banks increase with increasing depth. EC measurements of 1:1 extracts of samples taken from the 0-1 inch (0-25 mm) depth of the macro-grid varied from 2431 to 5752 µmhos/cm at 25°C having a range and mean of 3321 and 3004 µmhos/cm at 25°C respectively, and a coefficient of variation equal to 21.1 percent. The 1-6 inch (25-150 mm) depth grid, on the other hand, had a range of 8128 µmhos/cm at 25°C (2588 to 10,716), a mean of 4639 µmhos/cm at 25°C and a coefficient of variation equal to 39.1 percent, nearly twice as large as the previously referenced coefficient of variation. The results of a t-test caused the null hypothesis to be rejected at the 0.99 level that the macro-grid data at the two depths studied come from populations with the same mean. Although the coefficients of variation associated with the 0-1 and 1-6 inch (0-25 and 25-150 mm) depths of the micro-grid were not significantly different (13.1 percent versus 15.5 percent, respectively),

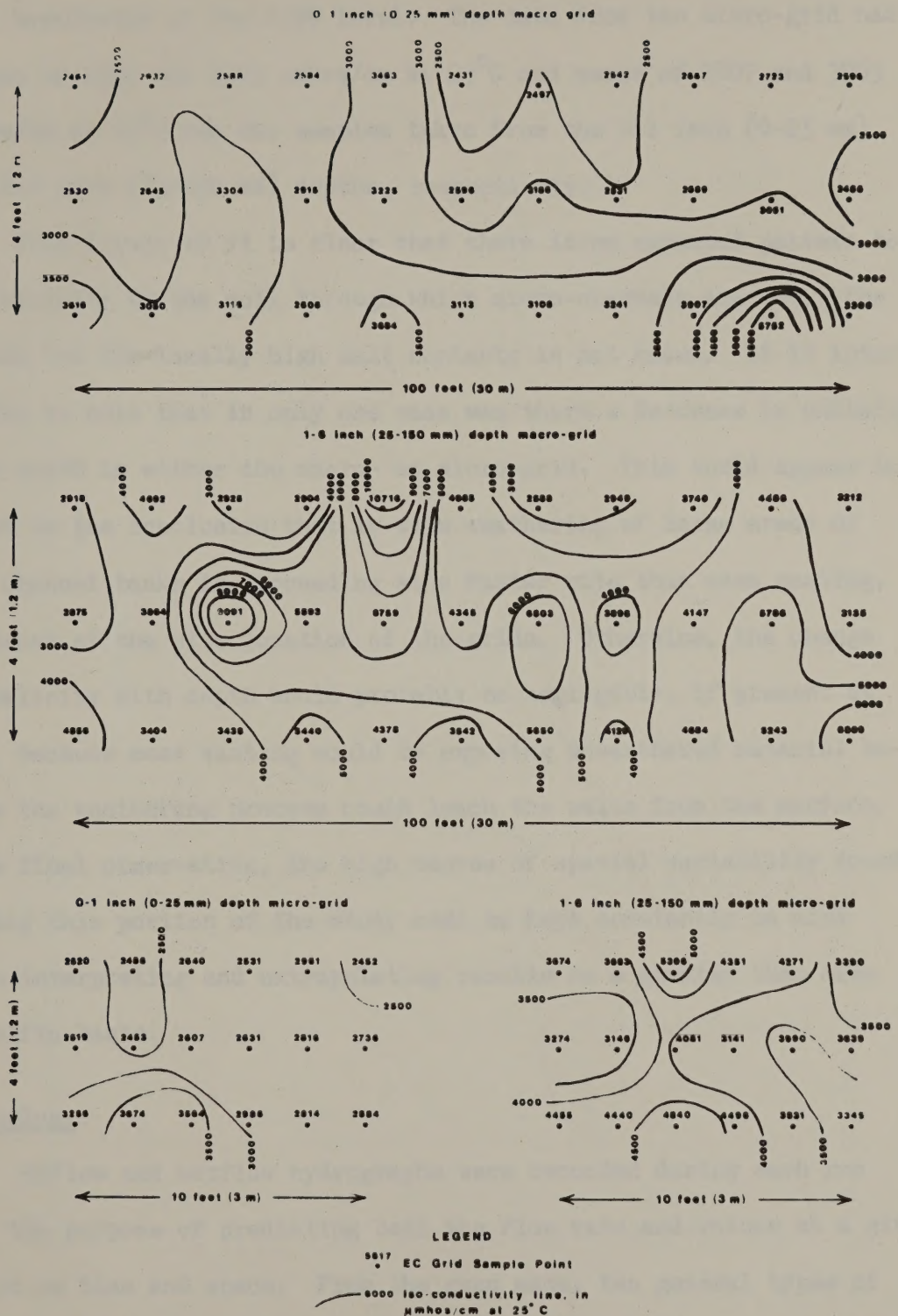
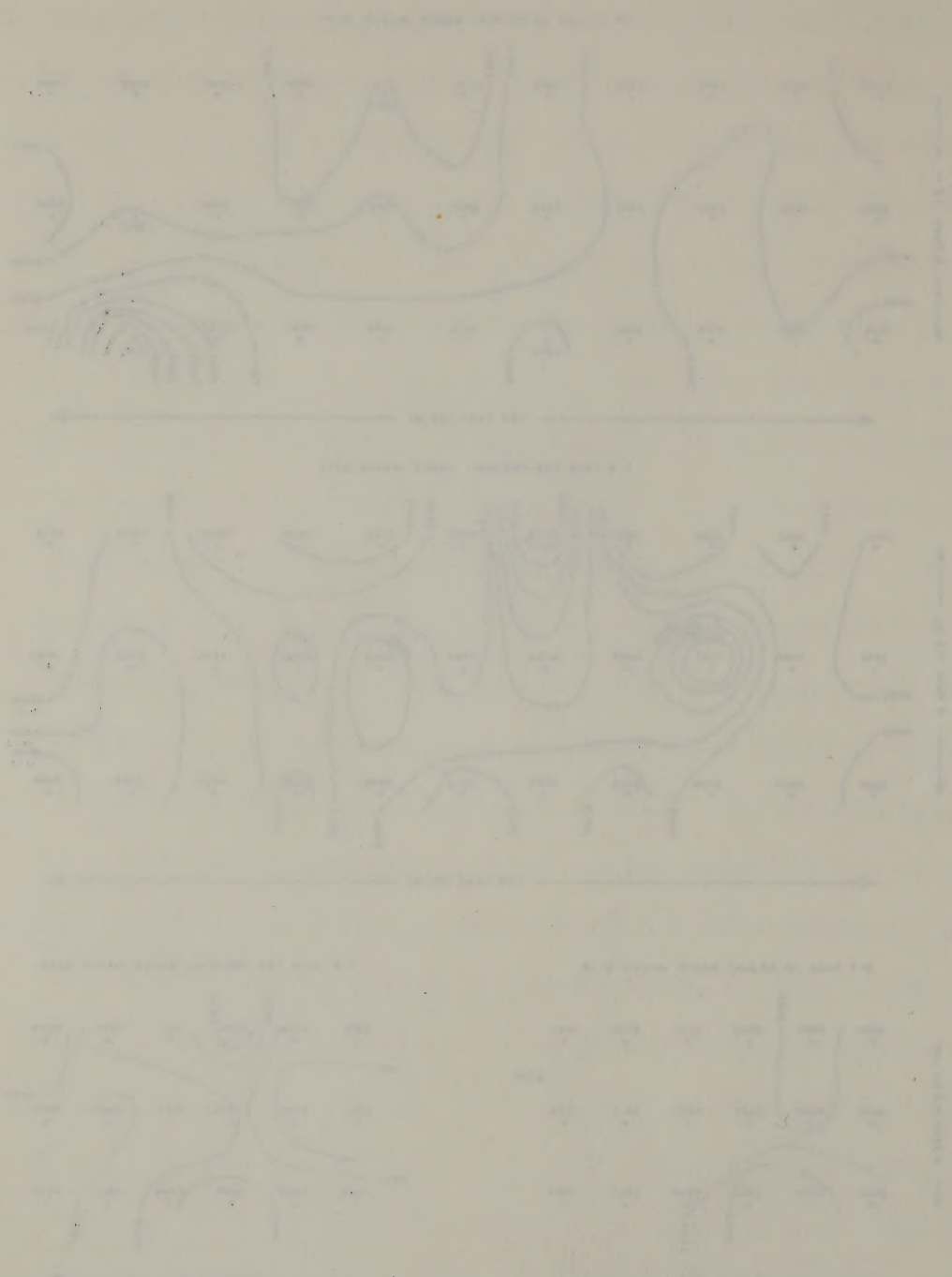

0-1 inch (0-25 mm) depth macro grid
4 feet (1.2 m)
100 feet (30 m)
1-6 inch (25-150 mm) depth macro-grid
4 feet (1.2 m)
100 feet (30 m)
0-1 inch (0-25 mm) depth micro-grid
4 feet (1.2 m)
10 feet (3 m)
1-6 inch (25-150 mm) depth micro-grid
10 feet (3 m)
LEGEND
EC Grid Sample Point
6000 Iso-conductivity line, in µmhos/cm at 25° C

Figure 10. Variation in the salinity of a channel bank downstream from site one



a t-test once again resulted in the rejection of the aforementioned null hypothesis at the 0.99 level. The data from the micro-grid had ranges of 1222 and 2165 μmhos/cm at 25°C and means of 2807 and 3963 μmhos/cm at 25°C for the samples taken from the 0-1 inch (0-25 mm) and 1-6 inch (25-150 mm) depths, respectively.

From figure 10 it is clear that there is no apparent pattern to the salinity of the soil through which micro-channels are cut. The reason for the locally high salt contents is not known. It is interesting to note that in only one case was there a decrease in salinity with depth in either the macro- or micro-grid. This would appear to point to the conclusion that in situ weathering of large areas of the channel banks is proceeding at a faster rate than mass wasting, at least at the site location of the grids. Otherwise, the change in salinity with depth would probably be negligible, if present at all, because mass wasting would be exposing unweathered material before the weathering process could leach the salts from the surface. As a final observation, the high degree of spatial variability found during this portion of the study must be kept constantly in mind when interpreting and extrapolating results on a greater than area specific basis.

Hydrology

Inflow and outflow hydrographs were recorded during each run for the purpose of predicting both the flow rate and volume at a given point in time and space. From the runs made, two general types of hydrograph pairs were observed (figure 11). The most prevalent hydrograph pair recorded (figure 11a), typical of runs at sites 1, 2, 3,

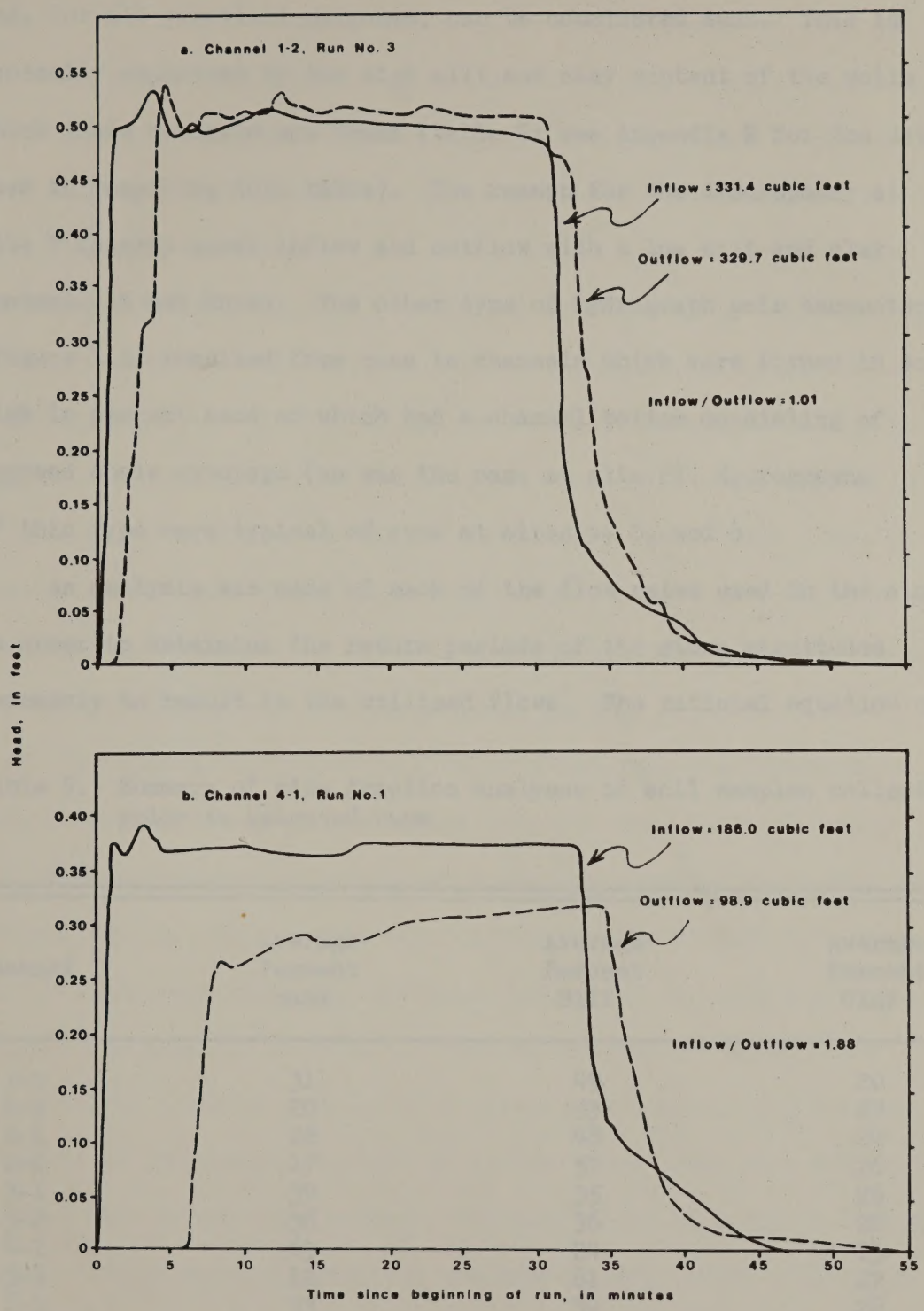
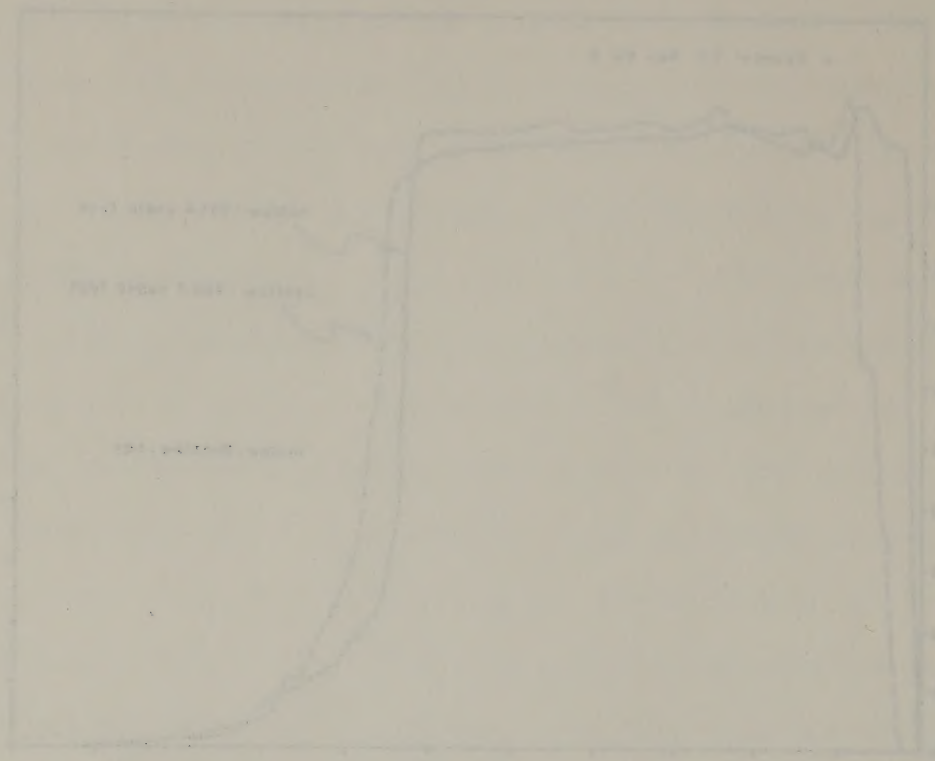
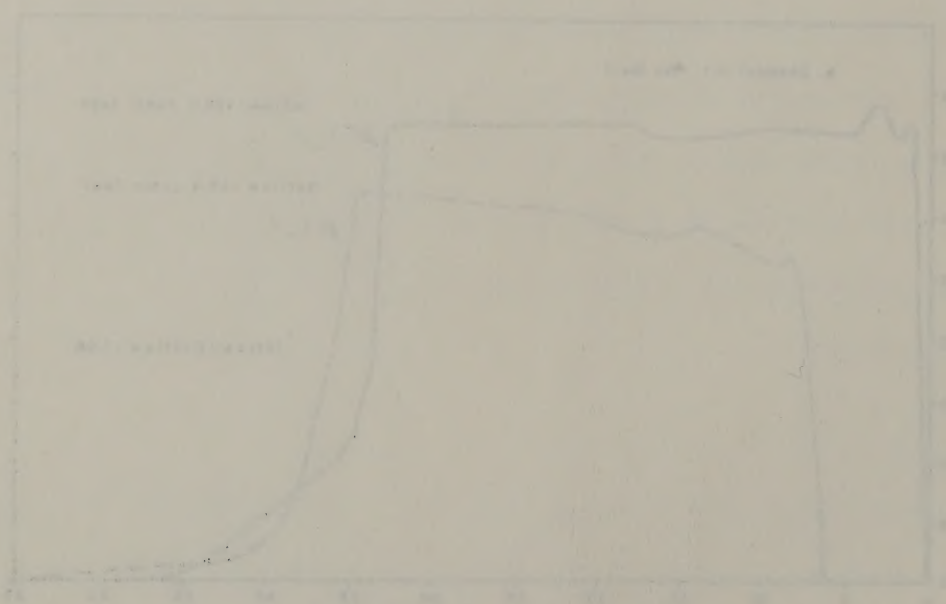

a. Channel 1-2, Run No. 3
Inflow : 331.4 cubic feet
Outflow : 329.7 cubic feet
Inflow / Outflow : 1.01
b. Channel 4-1, Run No. 1
Inflow : 186.0 cubic feet
Outflow : 98.9 cubic feet
Inflow / Outflow : 1.88
Head, in feet
Time since beginning of run, in minutes

Figure 11. Inflow and outflow hydrographs for (a) channel 1-2, run number 3 and (b) channel 4-1, run number 1





5, and 7, shows that the outflow was approximately equal to the inflow and, for all practical purposes, can be considered such. This is generally explained by the high silt and clay content of the soils in which these channels are found (table 9; see Appendix E for the data used in compiling this table). The reason for the discrepancy at site 7 (nearly equal inflow and outflow with a low silt and clay content) is not known. The other type of hydrograph pair encountered (figure 11b) resulted from runs in channels which were formed in soils high in percent sand or which had a channel bottom consisting of exposed shale outcrops (as was the case at site 6). Hydrographs of this type were typical of runs at sites 4, 6, and 8.

An analysis was made of each of the flow rates used in the study in order to determine the return periods of the storm magnitudes necessary to result in the utilized flows. The rational equation of

Table 9. Summary of size fraction analyses of soil samples collected prior to selected runs

Channel	Average Percent Sand	Average Percent Silt	Average Percent Clay
1-1	31	49	20
1-2	20	53	27
2-1	28	48	24
2-2	17	57	26
3-1	39	35	26
3-2	36	36	28
4-1	63	24	13
5-1	12	61	27
6-1	33	39	28
7-1	58	23	19
8-1	80	8	12

Kuichling (1889), the SCS runoff equation (Soil Conservation Service, 1972), and an infiltration excess model (see Appendix F) were all used in the test with the latter being chosen for the final analysis because of its more reasonable results and data based approach to physical reality (it was felt that the rational method underestimated while the SCS approach overestimated the return period, see table 10). The depth of precipitation necessary to produce the given flow was computed for each run and compared with values tabulated by Richardson (1971) of a duration equal to the flow duration for a determination of the return period. The station at Hiawatha, Utah was used for comparative purposes for sites 1 and 4 because of close proximity and similar elevation, respectively. The Price, Utah station served as a comparison in all other cases. Values for the infiltration constant were taken from nearby infiltration plots studied by Ponce (1975).

The results of the storm frequency analyses are presented in table 10. Note that the flow rates studied would have resulted from storms of relatively common occurance with the exception of those used at sites 1 and 4. The reasons for the high return periods calculated at these sites were the small drainage areas of site 1 and the high infiltration capacity of site 4. Because the runs at sites 5 and 7 were of a longer duration (60 and 50 minutes, respectively), the return periods of the storms required to create these flows were also slightly higher than normal. In general, however, table 10 suggests that the production of salt and sediment realized in this study would occur in nature under quite normal circumstances.

As a final observation, it was noted that channel scour lowered the channel bottom from zero to about $1\frac{1}{2}$ inches (0-38 mm) during each

Table 10. Results of storm frequency analyses for each channel and run

Channel	Run	Return Period, in years, by the Rational Method Approach	Infiltration Excess Model Approach	SCS Runoff Method Approach
1-1	1	3	71	220
	2	1+	18	53
	3	2	43	140
1-2	1	2	53	170
	2	1+	22	71
	3	6	180	670
2-1	1	< 1	3	4
	2	< 1	1+	2
	3	< 1	3	4
2-2	1	< 1	1+	1+
	2	< 1	1+	1+
	3	< 1	1+	1+
3-1	1	< 1	2	2
	2	< 1	1+	1+
	3	< 1	2	3
3-2	1	< 1	2	2
	2	< 1	1+	1+
	3	< 1	2	2
4-1	1	1+	53	150
5-1	1	< 1	5	11
6-1	1	< 1	2	4
7-1	1	< 1	6	45
8-1	1	< 1	4	35

Note: 1 acre = 0.4 hectare; 1 inch = 25.4 mm

run, the exact amount depending upon the particular channel and flow volume. A basin wide average of approximately one-half inch (13 mm) of scour resulted from each run. Thus, the collection of soil samples to a depth of one inch (25 mm) prior to each run not only allowed the channel to remain relatively undisturbed but also gave an estimate of the physical and chemical properties of the sediment that was transported downstream.

Water Quality

The results of chemical analyses of selected samples collected from the 100 foot (30 m) station of each channel during run number one are presented in figure 12 (see Appendix G for the results of all chemical analyses of water samples completed during the study). The ions in figure 12 have been grouped according to channel with anions on the left and cations on the right in order that a more complete identification of the chemical systems of concern might be made.

Three observations should be made regarding the figure. First, the upper and middle divisions of the Bluegate member of the Mancos shale (sites 1 and 5, respectively) appear to be the prime sources of salt within the Price River basin. This is somewhat in contradiction with the findings of Ponce (1975) who, in relation to overland flow, determined that the middle and lower portions of the Bluegate as well as the Mancos Undivided areas were the primary sources of salinity within the basin. The main reason for this discrepancy is undoubtedly the great degree of spatial variability previously mentioned. The Bluegate member, however, can still be considered the geologic type which contributes the greatest amount of salt to the Price River, the ultimate sink of all salts delivered within the system.

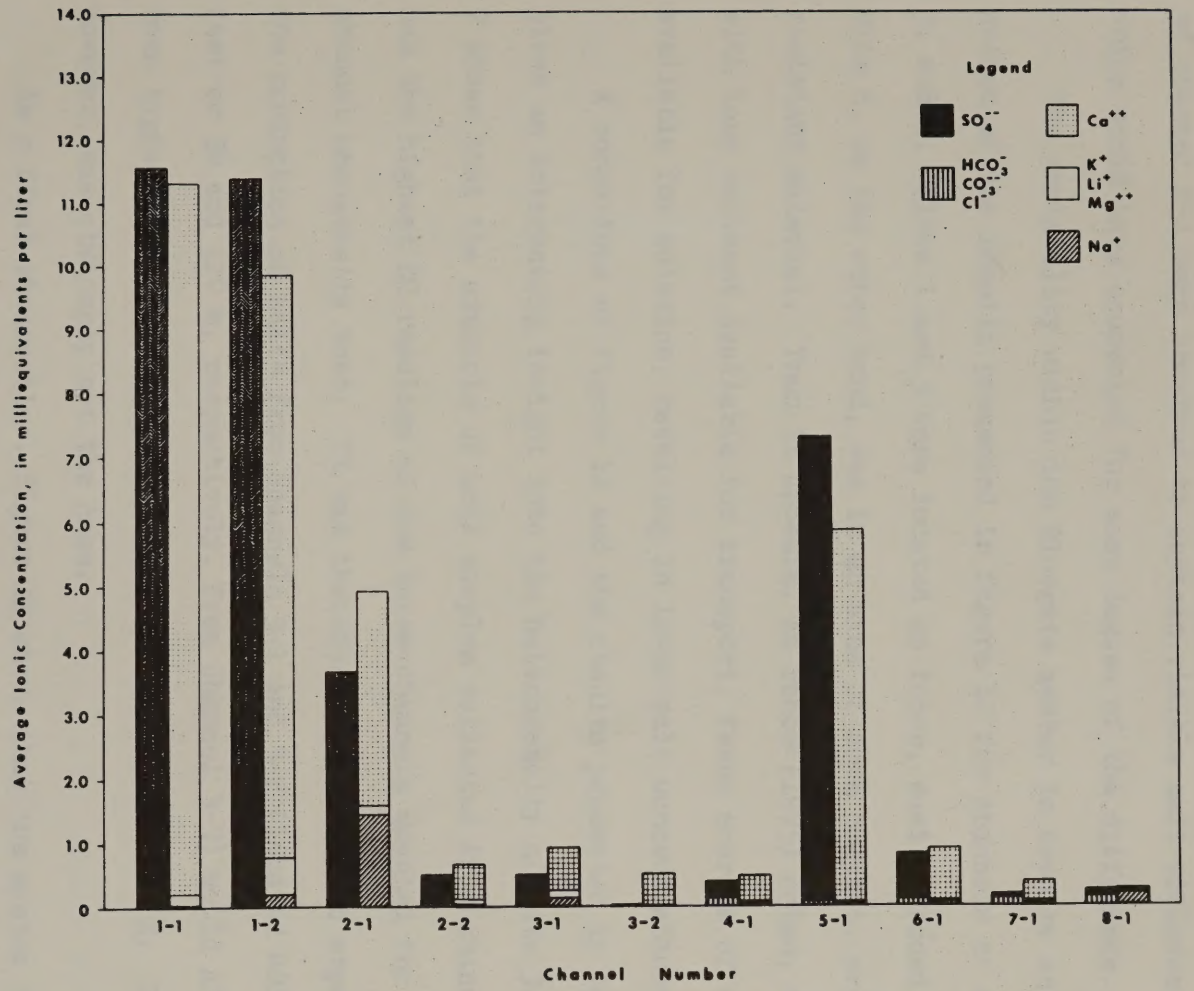


Figure 12. Average ionic concentration at the 100 foot (30 m) station during run number one in all channels during the first 30 minutes of flow

The second observation again concerns the degree of system variability. Notice that ionic concentrations from channel 2-1 were approximately seven times greater than those from channel 2-2 although the channels were located only 300 feet (90 m) apart. Sections of channel 2-1 were observed to contain visible salt efflorescence which would have accounted for some degree of the difference.

The variability within the Bluegate member is seen by an examination of the results presented in figure 12 for channels at sites 1, 5, and 6. Sites 1 and 5 were located on loose, easily eroded material. Site 6, on the other hand, was in an area of more compact, erosion-resistant material. Thus it appears, as Ponce (1975) noted, that with less sediment available for transport, fewer sources of salt are available for solution, resulting in lower salt concentrations.

A comparison of figure 12 and the results presented in table 7 gives an interesting insight into the heterogeneity of site 3. Table 7 shows that the extracts of soil samples collected from channel 3-3 has the highest EC readings of the three channels sampled for the channel homogeneity test. It was therefore reasonable to expect that the production of salts from channels 3-1 and 3-2 (located 400 and 100 feet or 30 and 120 m, respectively, from channel 3-3) would also have been higher than that resulting from runs at sites 1 and 2. This, however, was obviously not the case.

As a final observation, figure 12 shows that the system is generally calcium sulfate (gypsum) in type and that sodium, not lithium, is the dominate monovalent cation, which contradicts the findings of Whitmore (1976). Jurinak has indicated that analytical

error was the probable reason for the high lithium concentrations found by Whitmore.[6]

Table 11 gives the results of linear regression analyses of selected combinations of EC, TDS, and SS for the first run in all channels. Computed values of the correlation coefficient, r, were compared with the tabular values provided by Snedecor (1946) to test the validity of the null hypothesis that the sample comes from a population with a correlation coefficient equal to zero.

In general there appears to be good correlation between the parameters tested. A comparison of figure 12 and table 11 shows that those cases where the regression analysis failed to reject the null hypothesis are associated with channels of low salt content. As was previously mentioned, total dissolved solids concentrations were computed for runs two and three at sites 1, 2, and 3, using the information provided in table 11. EC was used as the index for TDS in all cases except channel 2-2 where SS was used because of the higher r value. It was later determined that EC probably would have provided as good an index as SS in the case of channel 2-2 since the coefficient of correlation is significantly different from zero at the 0.99 level in both cases.

Note that the slope of the line for the regressions of EC versus TDS is often greater than one. This is typical of systems high in gypsum due to the existence of the soluble ion pair $CaSO_4^{\circ}$ aqueous (Tanji, 1969). In addition, some salt was undoubtedly released from

---

[6] Jurinak, Jerome J., Professor of Soil Science and Biometeorology at Utah State University, personal communication dated October 1976.

Table 11. Results of linear regression analyses (Y = A + BX) of electrical conductivity versus total dissolved solids, suspended solids versus total dissolved solids, and electrical conductivity versus suspended solids for run number one in all channels

Channel	A, in milligrams per liter	B[(a)]	Standard Error of Estimate, in milligrams per liter	r^2	r	degrees of freedom	Level of Significance of r
Electrical conductivity (X) versus Total dissolved solids (Y)							
1-1	67.8	1.36	139.1	0.924	0.961	26	**
1-2	52.9	1.41	108.6	0.928	0.963	26	**
2-1	64.6	1.00	45.7	0.928	0.963	25	**
2-2	52.1	1.11	27.5	0.488	0.699	26	**
3-1	15.1	2.93	28.7	0.437	0.661	25	**
3-2	49.4	1.07	13.7	0.941	0.970	25	**
4-1	28.9	0.02	20.4	0.001	0.009	29	NS
5-1	-1.8	1.16	74.6	0.947	0.973	55	**
6-1	-12.3	0.85	11.2	0.788	0.888	23	**
7-1	5.2	0.91	10.8	0.480	0.693	34	**
8-1	2.6	0.59	5.5	0.288	0.537	25	**
Suspended solids (X) versus Total dissolved solids (Y)							
1-1	116.2	0.012	128.9	0.934	0.967	26	**
1-2	161.5	0.018	130.8	0.887	0.942	25	**
2-1	136.7	0.018	91.4	0.714	0.845	25	**
2-2	47.0	0.002	25.6	0.558	0.767	26	**
3-1	23.4	0.002	31.3	0.327	0.572	25	**
3-2	77.5	0.003	55.9	0.022	0.149	25	NS
4-1	13.6	0.002	15.2	0.445	0.667	29	**
5-1	-22.1	0.023	103.7	0.897	0.947	55	**
6-1	7.9	0.012	23.3	0.074	0.271	23	NS
7-1	1.3	0.002	9.4	0.605	0.778	34	**
8-1	2.8	0.003	5.1	0.390	0.624	25	**
Electrical conductivity (X) versus Suspended solids (Y)							
1-1	-559.8	107.5	17406.7	0.828	0.910	26	**
1-2	-3516.7	67.8	8544.4	0.827	0.909	25	**
2-1	2290.7	38.2	5281.6	0.586	0.766	25	**
2-2	2420.4	466.0	5023.5	0.835	0.914	26	**
3-1	791.6	980.4	6643.3	0.617	0.785	25	**
3-2	2471.8	7.8	2601.0	0.023	0.152	25	NS
4-1	2923.2	336.6	7365.2	0.138	0.371	30	*
5-1	2507.4	44.7	5758.1	0.816	0.903	55	**
6-1	325.2	4.2	533.6	0.039	0.197	23	NS
7-1	1768.2	407.5	2413.7	0.789	0.888	34	**
8-1	353.6	163.1	1144.5	0.421	0.649	25	**

(a) - in milligrams per liter per mho/cm at 25°C or unitless, depending upon the comparison

NS - failed to reject the null hypothesis at the 0.95 level

* - rejected the null hypothesis at the 0.95 level

** - rejected the null hypothesis at the 0.99 level

Note: EC in µmhos/cm at 25°C; TDS in milligrams per liter; SS in milligrams per liter

the sediment following the conductivity measurement and prior to filtration. This was presumably only a small amount, however (see Whitmore, 1976).

The results presented in table 11 show that a good correlation exists between SS and TDS. This supports the findings of Ponce (1975) and Whitmore (1976) and suggests that at least a portion of the salt produced during an event is inherently associated with the sediment particles. As sediment is made available through scouring of the channel bottom and mass wasting of the channel banks, the amount of salt available for dissolution is also proportionately increased.

As a measure of the reliability of EC as an index of ionic concentration, linear regressions of the average electrical conductivity versus the average concentration of each ion measured at the 100 foot (30 m) station were carried out for all channels and runs. The results, presented in table 12, show that EC is a significant indicator of ionic concentration with the exception of bicarbonate and chloride ions. A possible explanation for the lack of correlation in these two cases is the fact that these ions appeared only sporadically and then only in small quantities. In general, however, from the results presented in tables 11 and 12, EC can be considered a good index of salt and sediment production within the Price River basin.

As was mentioned, estimates of suspended solids and total dissolved solids were made of each sample collected. All results followed the same basic pattern and thus the data presented in figure 13 can be considered typical of all of the channels studied. Notice that there is a general increase in both SS and TDS with distance downstream and a decrease with time, indicating that overland flow and channel salt release

Table 12. Results of linear regression analyses (Y = A + BX) of average electrical conductivity versus average ionic concentration at the 100 foot (30 m) station of all channels during all runs

Ion	A, in milliequivalents per liter	B(a)	Standard Error of Estimate, in milliequivalents per liter	r^2	r	Level of Significance of r
HCO_3^-	0.016	$-9(10^{-6})$	0.017	0.015	0.124	NS
CL^-	0.047	$-4(10^{-5})$	0.043	0.049	0.221	NS
SO_4^{2-}	-0.252	$2(10^{-2})$	1.735	0.865	0.930	**
Na^+	-0.019	$1(10^{-3})$	0.533	0.284	0.533	**
K^+	0.027	$2(10^{-4})$	0.102	0.195	0.441	*
Li^+	0.0002	$5(10^{-6})$	0.001	0.652	0.808	**
Mg^{2+}	-0.006	$1(10^{-4})$	0.035	0.363	0.602	**
Ca^{2+}	0.103	$1(10^{-2})$	1.720	0.806	0.898	**

(a) - in milliequivalents per liter per µmho/cm at 25°C
NS - failed to reject the null hypothesis at the 0.95 level
* - rejected the null hypothesis at the 0.95 level
** - rejected the null hypothesis at the 0.99 level

processes are similar (see Ponce, 1975). The increase with distance results from the mere increase in salt and sediment with which the water comes into contact as the area of contact increases. The shape of the concentration curves with time indicates that in relation to both SS and TDS a quasiequilibrium concentration was reached after approximately 20 or 25 minutes. This, it will be recalled, differs somewhat from the findings of Whitmore (1976) who concluded that a period of only about two minutes is required before an apparent

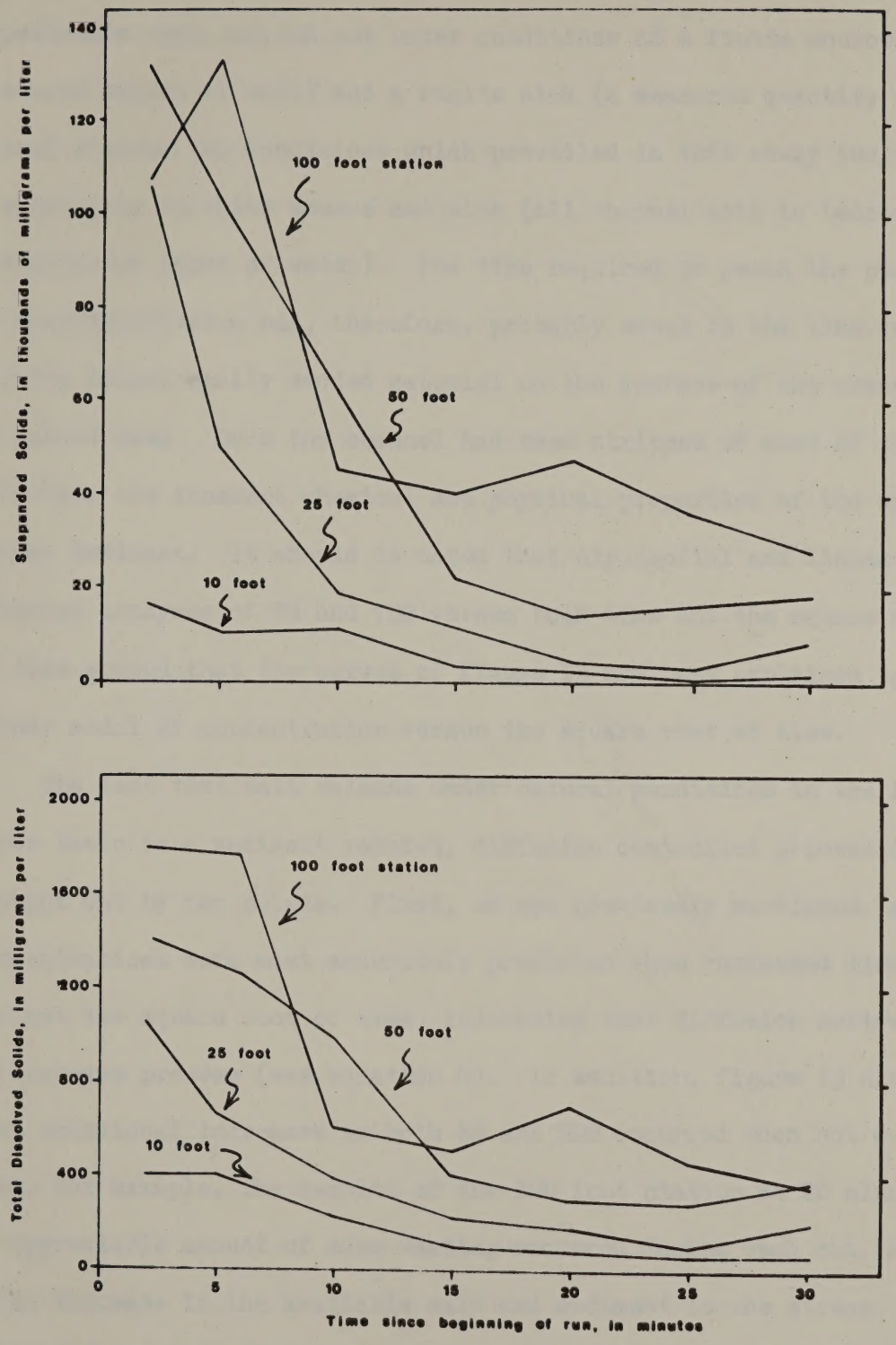
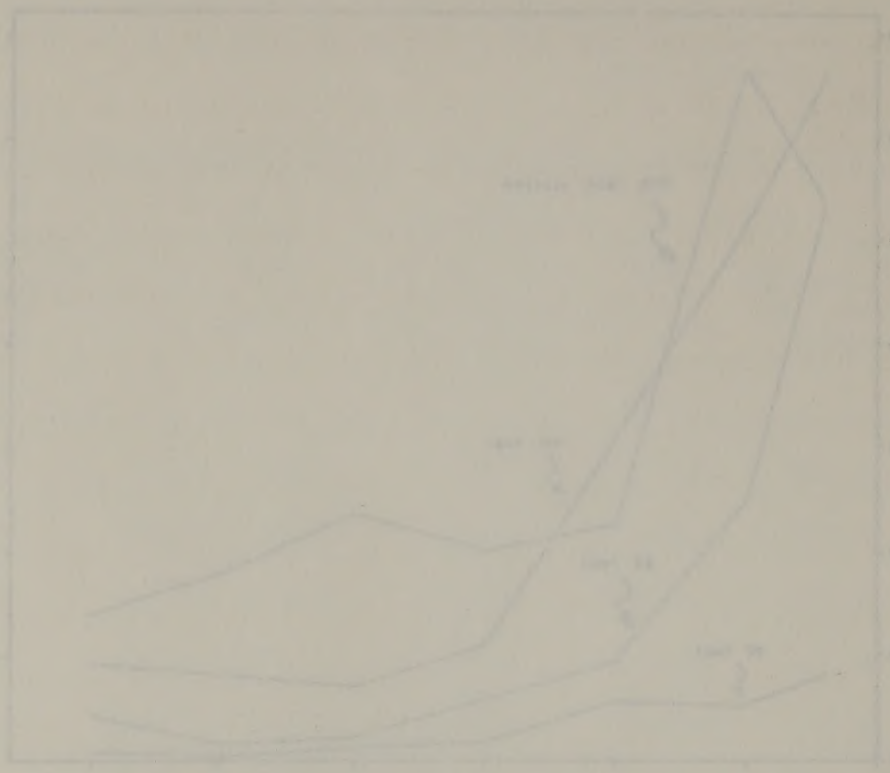
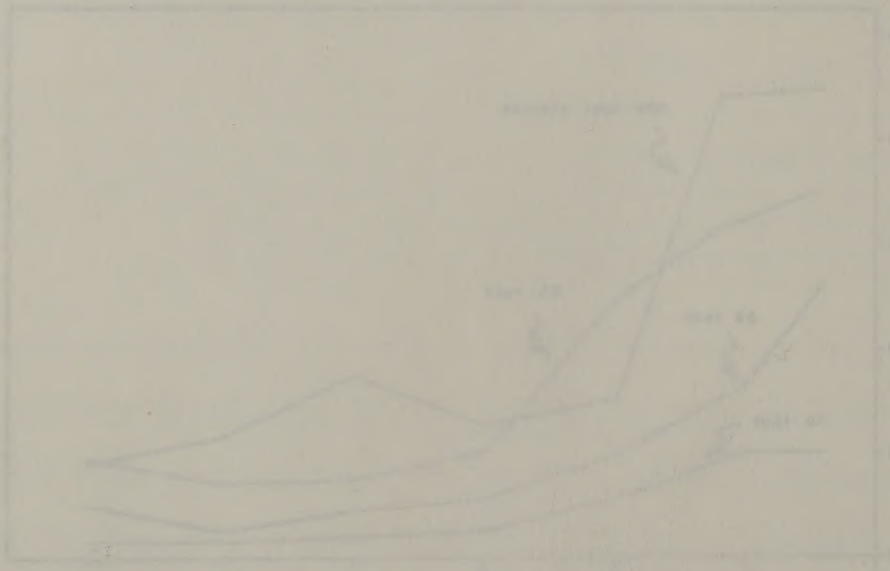


Figure 13. Suspended solids and total dissolved solids concentrations through time for channel 1-1, run number 1





equilibrium is reached. It must be remembered, however, that Whitmore's experiments were carried out under conditions of a finite source (a measured amount of soil) and a finite sink (a measured quantity of water) whereas the conditions which prevailed in this study included a relatively infinite source and sink (all channel soil to bedrock and a continuous input of water). The time required to reach the period of quasiequilibrium was, therefore, probably equal to the time required for the loose, easily eroded material on the surface of the channel to be washed away. Once the channel had been stripped of most of this material, the inherent chemical and physical properties of the soil became dominant. It should be noted that exponential and linear regression analyses of SS and TDS versus both time and the square root of time showed that the curves of figure 13 are best explained by a linear model of concentration versus the square root of time.

The fact that salt release under natural conditions in the Price River basin is a sediment related, diffusion controlled process is brought out by two points. First, as was previously mentioned, salt concentrations were most accurately predicted when regressed linearly against the square root of time, indicating that diffusion controls the release process (see equation 4). In addition, figure 13 shows that occasional increases in both SS and TDS occurred when not expected (see, for example, the results of the 100 foot station at 20 minutes). An appreciable amount of mass wasting occurred during each run, resulting in an increase in the available salt and sediment in the stream. The fact that these blips in TDS and SS occured simultaneously and that the concentration curves followed the same general decay path suggests that

salt release is dependant upon two sediment related mechanisms:

1. A portion of the salt exists as precipitates and enters quickly into solution and

2. The remainder is associated with the more resistant mineral fraction and is released slowly after coming into contact with water. This agrees with the conclusions of Whitmore (1976). As water first comes into contact with a given section of channel, either because of the beginning of a runoff event or the mass wasting which results from the event, the free salt crystals dissolve rapidly while the salts which are more inherent in the structure of the sediment are released slowly. Thus, during the period of quasiequilibrium the latter process most likely dominates while the former mechanism is prevalent during the initial stages of an event.

A limited amount of EC data was collected downstream from the test sections and converted to TDS using the relationships found in table 11. The data, presented in figure 14 for three of the channels, suggest that for flow distances longer than 800 or 1000 feet (240 or 300 m) the total dissolved solids concentration remains relatively constant. It should be noted that water had been flowing at each sample point indicated in figure 14 for a period of at least 10 to 15 minutes, thus allowing the system at each downstream point to reach a state somewhat indicative of that found upstream where the water had been in contact with the channel for a longer period of time. It is theorized that the flow length required to reach a state of quasiequilibrium is dependant upon the degree of chemical saturation of the water and the salt content of the channel. The former is presumably binding

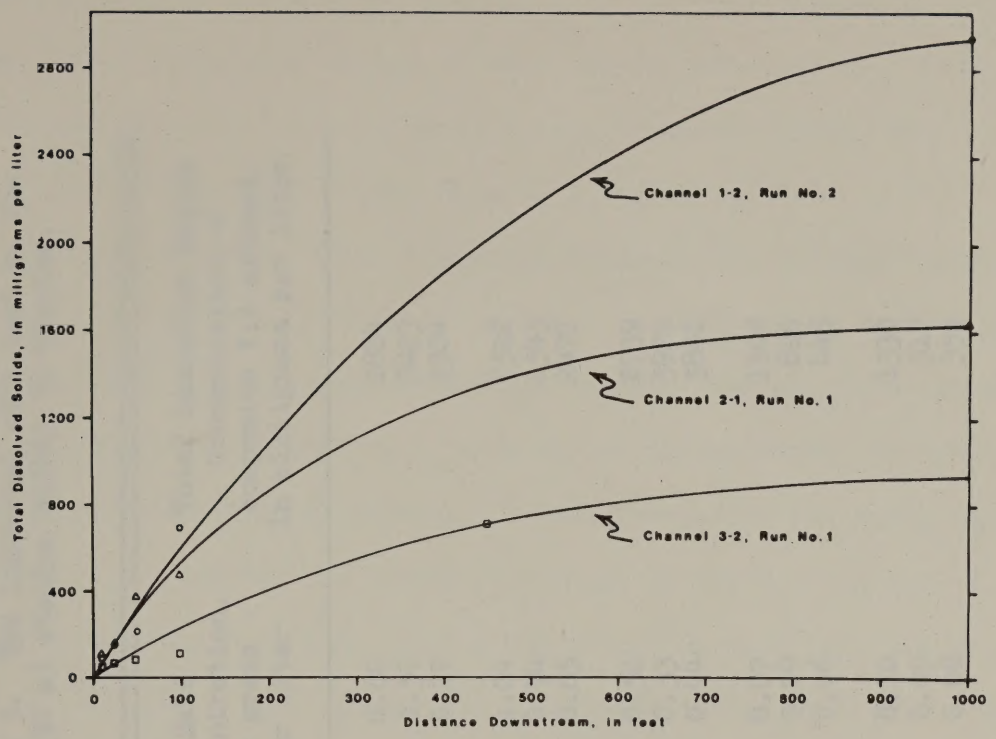


Figure 14. Effects of flow distance on total dissolved solids concentration for channels 1-2 (run 2), 2-1 (run 1), and 3-2 (run 1). 1 foot = 0.305 m

in salty systems (i.e. the Bluegate member of the Mancos shale) while the latter becomes binding in less saline areas.

An investigation into the effect of an event on the salt output of subsequent events lead to inconclusive results. Table 13 shows that the salt load concentration varied little from run to run at sites 2 and 3 even though there were great changes in the salt content of the surface inch of the channel bottom (as indexed by the TDS concentration of the composite 1:1 soil extract). This would indicate that salt loads are highly flow dependant. However, in the case of site 1, marked decreases in the salt load concentration occured with relatively small changes in the salinity of the channel bottom. It is apparent that efflorescent deposits were increased as a result of

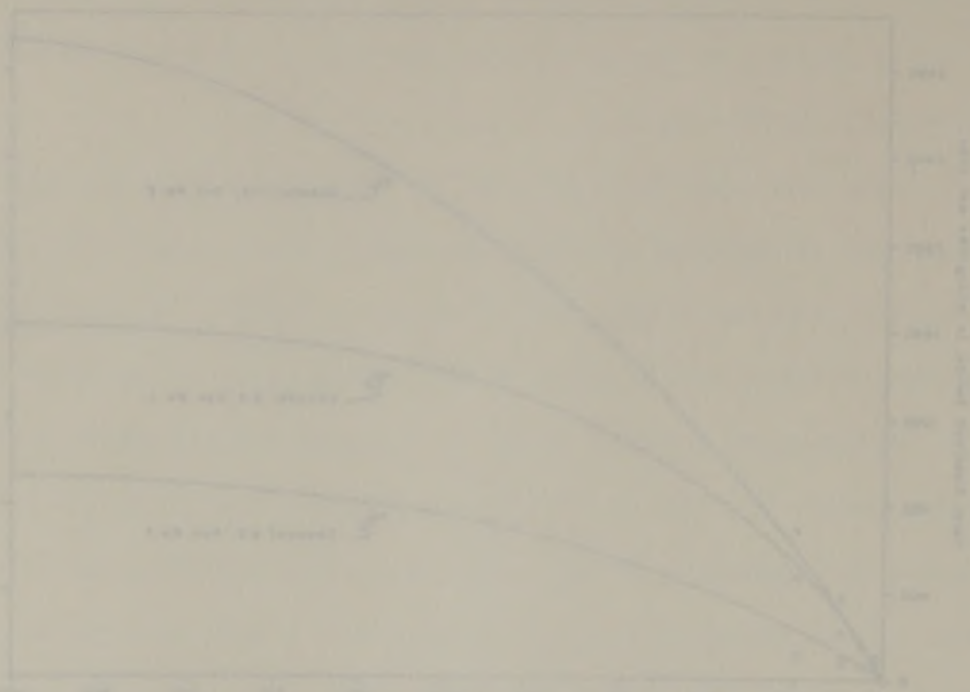


Table 13. Salt loads per unit flow volume and total dissolved solids concentrations of composite one-to-one extracts of soil samples collected prior to runs for each channel and run at sites 1, 2, and 3. The indicated salt load is the total amount produced at the 100 foot (30 m) station within 30 minutes.

Channel	Run	Flow Volume, in cubic meters	Salt Load, in kilograms	Salt Concentration, in grams per liter	Total Dissolved Solids Concentration of composite 1:1 extract, in milligrams per liter
1-1	1	5.54	4.34	0.80	2884
	2	2.40	1.19	0.50	2423
	3	5.18	1.52	0.29	2304
1-2	1	4.77	4.95	1.04	2522
	2	2.46	1.81	0.74	2545
	3	8.89	5.76	0.65	2474
2-1	1	5.49	2.85	0.52	2739
	2	2.36	1.24	0.53	5920
	3	5.01	2.21	0.44	5841
2-2	1	5.03	0.33	0.07	1108
	2	2.11	0.18	0.09	626
	3	7.71	0.49	0.06	448
3-1	1	5.22	0.53	0.10	1330
	2	1.92	0.17	0.09	317
	3	6.12	0.49	0.08	353
3-2	1	3.67	0.57	0.16	2009
	2	1.62	0.24	0.15	1443
	3	4.54	0.50	0.11	1427

flows in selected cases (i.e. channel 2-1) but this phenomenon did not appear to be widespread enough to make general conclusions. Thus it is evident that past history plays a role in micro-channel salt output, but this role varies from site to site.

The production of total suspended sediment and bedload followed the same general trends noted in relation to salt output in that there appeared to be no definite correlation between load and flow volume from run to run. A comparison, however, of the suspended sediment load and bedload produced during all runs throughout the basin showed that bedload accounted for about 40 percent of the total sediment measured, making it an important solid contribution within the watershed.

In order to better define the factors affecting salt production from micro-channels, various channel and flow parameters were compared with total salt output (concentration times flow volume). The data presented in figure 15, standardized at 30 minutes and 100 feet (30 m) where necessary, show that salt load is relatively insensitive to flow parameters, which might be expected considering the results given in table 13 and the interaction between each of the variables. In testing the null hypothesis that the data came from a population with a linear correlation coefficient of zero, the r values listed in the figure would need to be greater than 0.352 or 0.413 to reject the hypothesis at the 0.90 or 0.95 level respectively (Snedecor, 1946; 21 degrees of freedom). Thus only the hydraulic radius appears to be marginally linearly related to salt production.

Figure 16 presents the results of comparisons between salt output and channel parameters. In order to be significantly different from

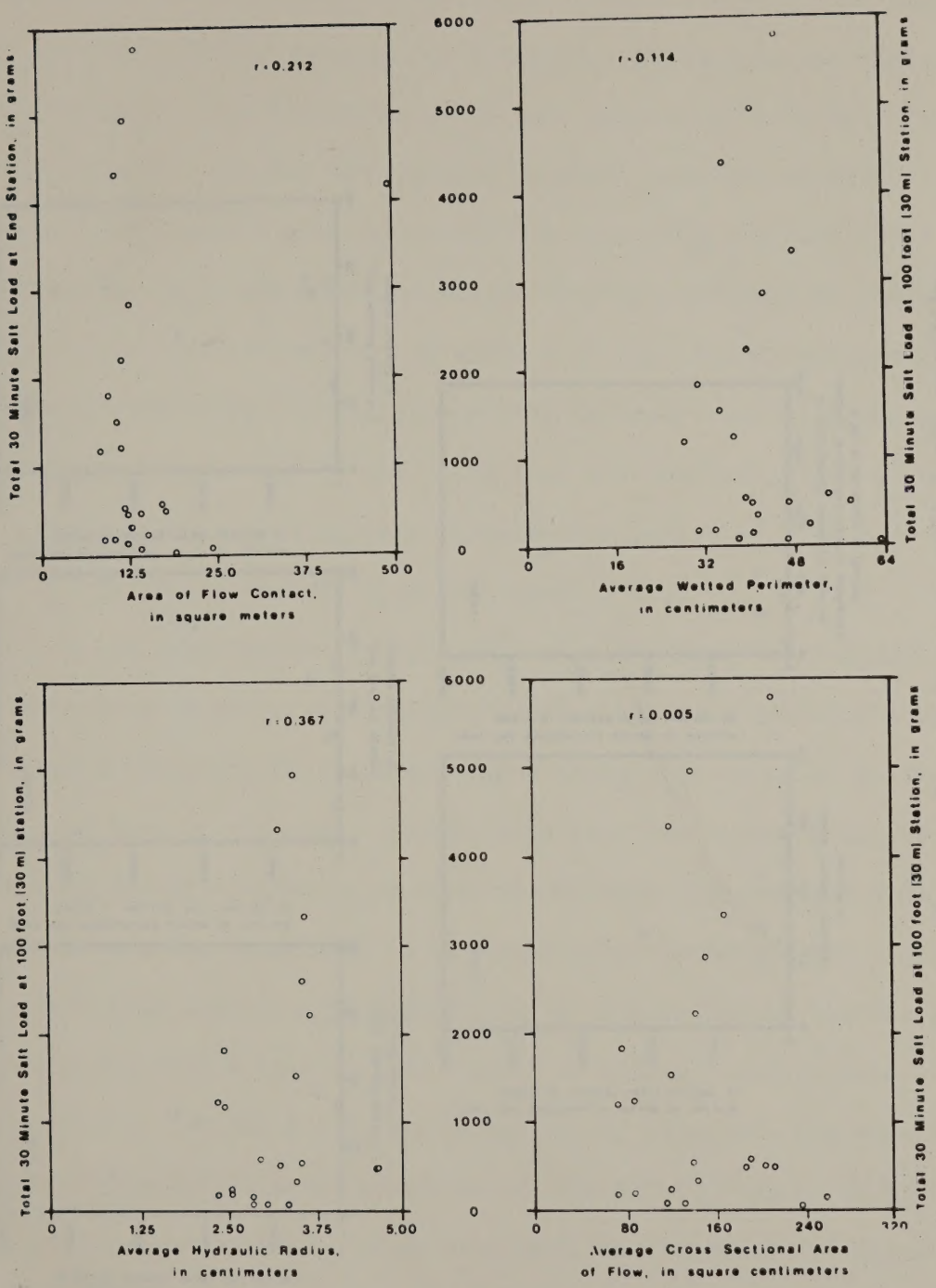

r = 0.212
Total 30 Minute Salt Load at End Station, in grams
Area of Flow Contact, in square meters
r = 0.114
Total 30 Minute Salt Load at 100 foot (30 m) Station, in grams
Average Wetted Perimeter, in centimeters
r = 0.367
Total 30 Minute Salt Load at 100 foot (30 m) station, in grams
Average Hydraulic Radius, in centimeters
r = 0.005
Total 30 Minute Salt Load at 100 foot (30 m) Station, in grams
Average Cross Sectional Area of Flow, in square centimeters

Figure 15. Effects of flow parameters on salt loads resulting from each run in each channel

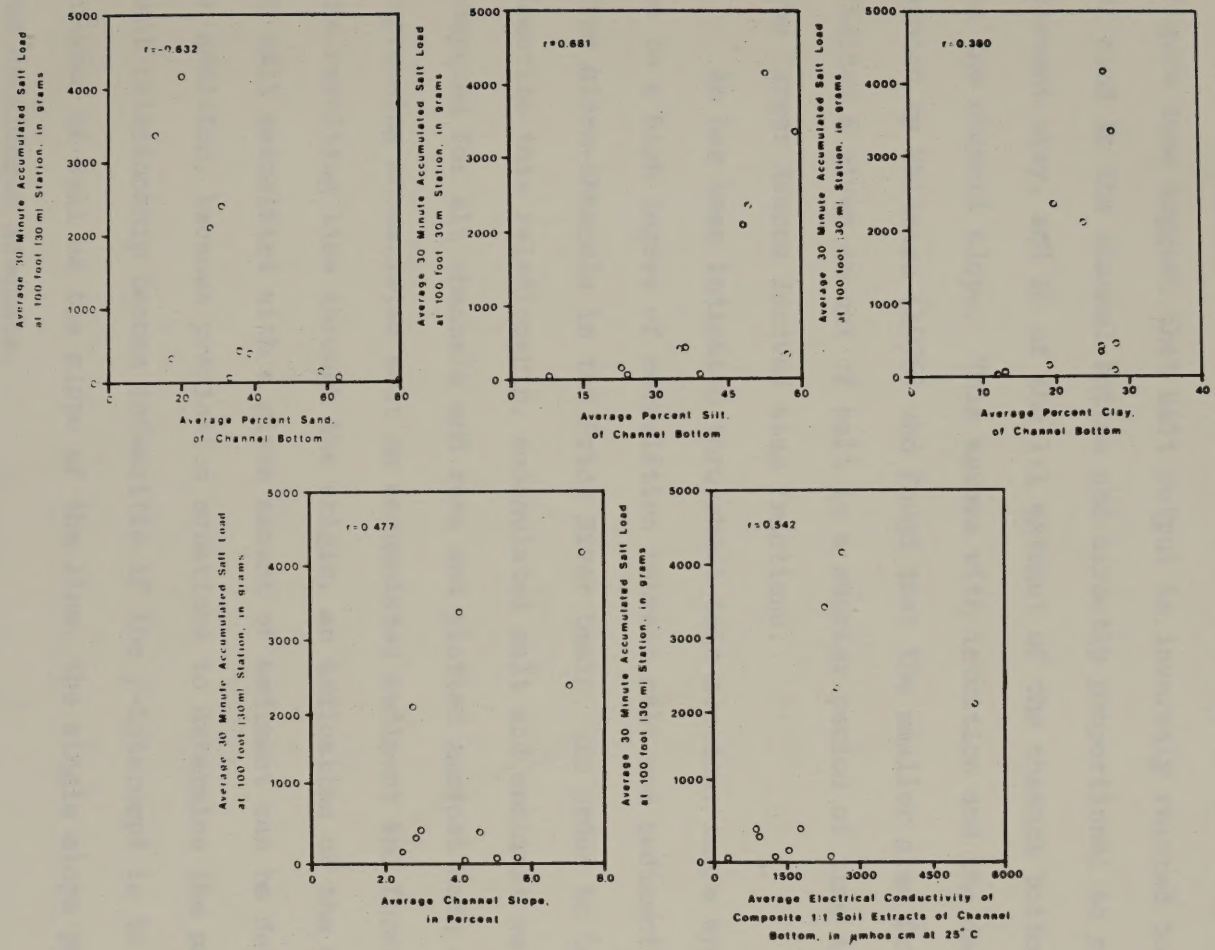

r=-0.632
Average 30 Minute Accumulated Salt Load at 100 foot 30 mi Station, in grams
Average Percent Sand, of Channel Bottom
r=0.681
Average Percent Silt, of Channel Bottom
r=0.380
Average Percent Clay, of Channel Bottom
r=0.477
Average Channel Slope, in Percent
r=0.542
Average Electrical Conductivity of Composite 1:1 Soil Extracts of Channel Bottom, in μmhos cm at 25° C

Figure 16. Effects of channel parameters on salt loads resulting from each run in each channel

zero at the 0.90 or 0.95 level, the indicated values of the linear correlation coefficient must be greater than 0.521 or 0.602, respectively (Snedecor, 1946; 9 degrees of freedom). It is apparent that channel factors have a greater influence on salt production than flow factors even though the linear relationship is still somewhat marginal. The figure does suggest that salt output is inversely related to the percent of sand in the channel bottom and directly proportional to percent silt, percent clay, and EC of the 1:1 extract of the channel bottom as well as the channel slope. This agrees with intuition and the data presented by Whitmore (1976) who found that the smaller size fractions yielded a given amount of salt in a shorter period of time than did the larger Mancos derived size fractions.

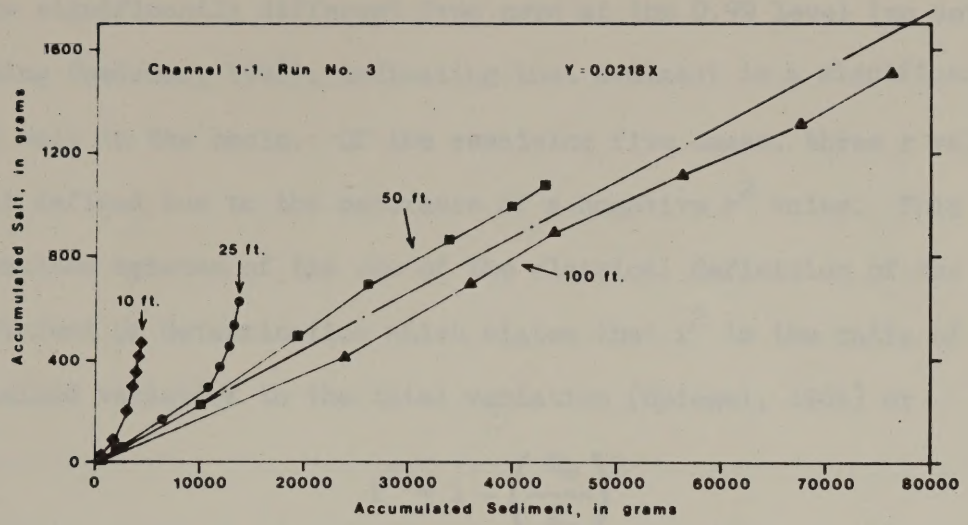
As has been indicated throughout this section, there appears to be a high degree of correlation between salt and sediment production from micro-channels in the Price River basin. In order to better describe this relationship, accumulated salt and sediment weights were computed for all channels and runs and plotted against each other. By regressing accumulated salt on accumulated sediment and force-fitting the resulting line through the origin, an indication of the amount of salt associated with a given amount of sediment can be determined. In addition, because prediction equations to determine the salt-sediment relationship become infeasible if the y-intercept is to be calculated as well as the slope of the line, the single slope parameter was considered adequate.

Table 14 presents the results of salt-sediment regression analyses while figure 17 displays graphically the results of two representative

Table 14. Results of linear regressions through the origin (Y = BX) of accumulated sediment (X) versus accumulated salt (Y) for all channels and runs

Channel	Run	B	S_e, in grams	r^2	r	Degrees of freedom	Level of significance of r
1-1	1	0.0139	226.2	0.967	0.984	26	**
1-1	2	0.0151	142.7	0.796	0.892	25	**
1-1	3	0.0218	165.1	0.835	0.914	26	**
1-2	1	0.0239	281.6	0.952	0.976	26	**
1-2	2	0.0252	156.1	0.878	0.937	26	**
1-2	3	0.0356	601.2	0.825	0.908	26	**
2-1	1	0.0260	251.1	0.907	0.952	25	**
2-1	2	0.0279	107.6	0.903	0.950	25	**
2-1	3	0.0318	244.8	0.839	0.916	25	**
2-2	1	0.0050	119.1	0.064	0.254	26	NS
2-2	2	0.0058	38.4	0.395	0.628	25	**
2-2	3	0.0071	103.3	0.458	0.677	26	**
3-1	1	0.0037	33.4	0.929	0.964	25	**
3-1	2	0.0090	49.6	-0.100	nd	25	nd
3-1	3	0.0089	109.3	0.342	0.585	26	**
3-2	1	0.0225	155.7	-0.084	nd	25	nd
3-2	2	0.0400	31.3	0.767	0.876	24	**
3-2	3	0.0431	121.1	0.212	0.461	25	*
4-1	1	0.0030	30.5	0.517	0.719	30	**
5-1	1	0.0226	281.7	0.981	0.991	55	**
6-1	1	0.0142	17.5	-0.281	nd	23	nd
7-1	1	0.0028	39.1	0.692	0.832	33	**
8-1	1	0.0047	6.6	0.711	0.843	25	**

NS - r not significantly different from zero at 0.95 level
* - r significantly different from zero at 0.95 level
** - r significantly different from zero at 0.99 level
nd - r not defined



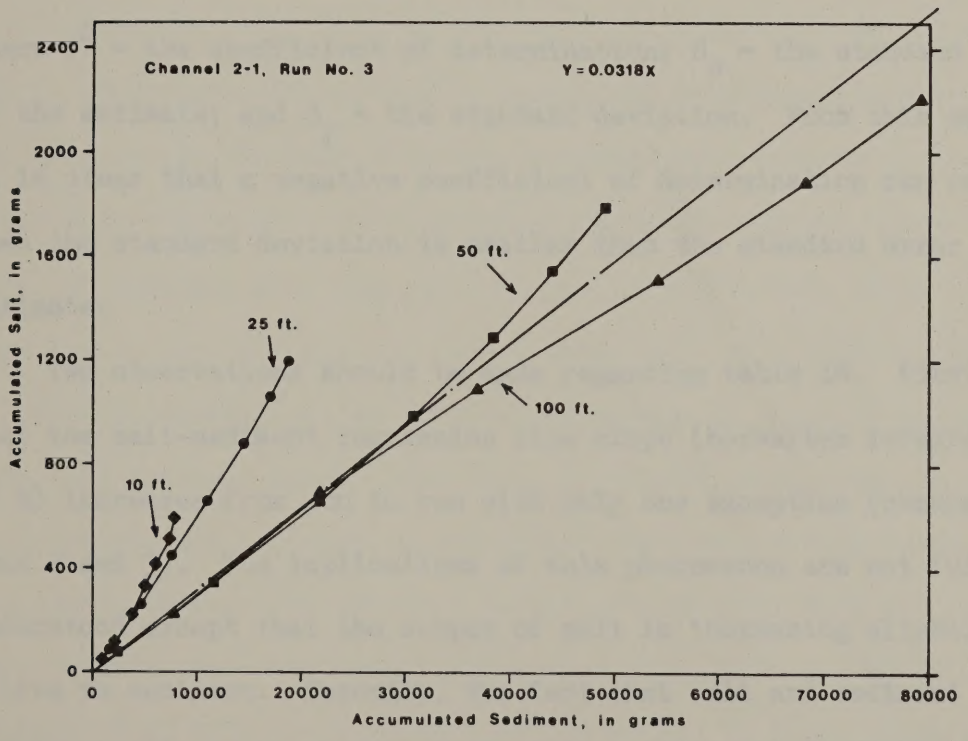
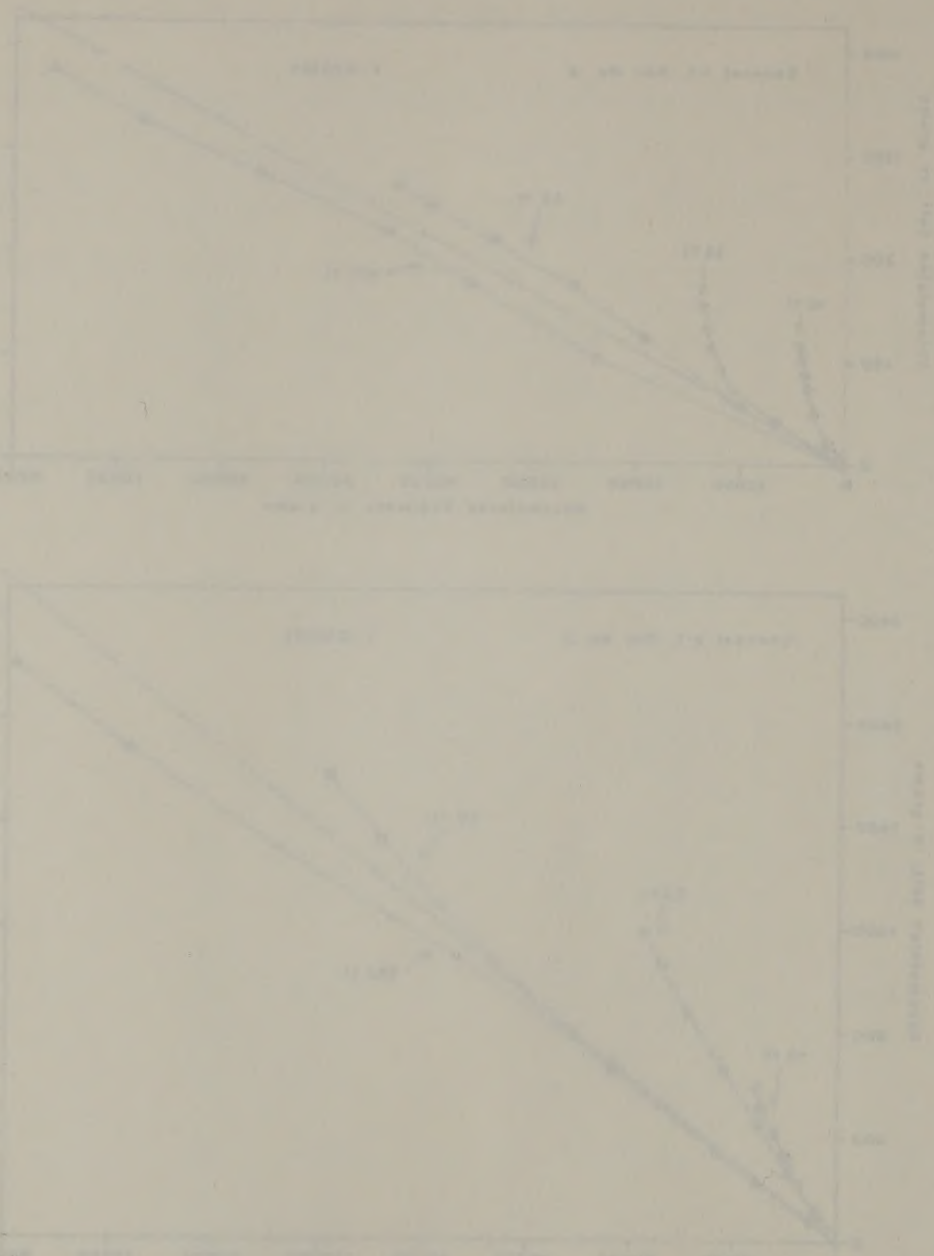


Figure 17. Accumulated sediment versus accumulated salt for channels 1-1 and 2-1, run number 3



cases. Notice from table 14 that 18 of the 23 correlation coefficients are significantly different from zero at the 0.99 level (as determined using Snedecor, 1946), indicating that sediment is a significant index of salt in the basin. Of the remaining five cases, three r values are not defined due to the occurance of a negative r^2 value. This has resulted because of the use of the classical definition of the coefficient of determination which states that r^2 is the ratio of the explained variation to the total variation (Spiegel, 1961) or

$$r^2 = 1 - \left(\frac{S_e}{S_y}\right)^2 \qquad (6)$$

where r^2 = the coefficient of determination; S_e = the standard error of the estimate; and S_y = the standard deviation. From this equation it is clear that a negative coefficient of determination can result when the standard deviation is smaller than the standard error of the estimate.

Two observations should be made regarding table 14. First, notice that the salt-sediment regression line slope (hereafter referred to as B) increases from run to run with only one exception (channel 3-1, runs 2 and 3). The implications of this phenomenon are not fully understood except that the output of salt is increasing slightly relative to sediment. Secondly, the fact that salt and sediment are highly correlated should not imply a direct cause and effect relationship between the two. The data does, however, suggest that the same mechanisms which produce sediment also produce salt. At any given point in time and space, the salt in a stream may be the result of dissolution of either readily available surface salts (i.e. evaporites)

or those salts more structurally a part of the sediment.

Figure 17 shows that the salt-sediment ratio tends to decrease with distance downstream and increase with time. This implies that the rate of sediment pickup decreases at a faster rate than the salt pickup rate. During the course of various runs it was observed that the water at the 10 and 25 foot (3 and 8 m) stations became quite clear relative to sediment after approximately 20 or 25 minutes. Salt, however, continued to enter solution at a seemingly more steady rate, thus increasing the salt load relative to the sediment load at these points. Although this would tend to invalidate the results presented in table 14 for long duration events, it is felt that the short durations studied are typical of the runoff phenomena found in the basin. Even in the case of longer duration runs (channel 5-1 and 7-1), there appeared to be little change in the salt-sediment ratio through time for stations more than 50 feet (15 m) downstream, indicating that the downstream decrease in the ratio does not continue indefinately.

Table 15 summarizes the B values appearing in table 14 by channel, site, and geologic type. Note that, by weight, salt tends to be one to three percent as large as sediment. The basin wide average for all Mancos sites (1.86 percent) corresponds closely with the column test of Whitmore (1976) who found that a given Mancos derived soil was capable of yielding 1.89 percent of its weight in salt. However, as previously explained, these numbers differ somewhat in their respective meanings because of the fact that the micro-channel study dealt with an ever-changing system of salt and soil because of channel bed scour and mass wasting whereas the column test of Whitmore utilized a fixed, isolated quantity of soil.

Table 15. B value summarization for various channels, sites, and geologic types in the Price River basin

Comparison	Mean B value	Standard Deviation	Coefficient of Variation
Channel 1-1, all runs	0.0169	0.0043	0.254
Channel 1-2, all runs	0.0282	0.0064	0.227
Site 1, all runs	0.0226	0.0079	0.349
Channel 2-1, all runs	0.0286	0.0030	0.104
Channel 2-2, all runs	0.0060	0.0011	0.178
Site 2, all runs	0.0173	0.0125	0.726
Channel 3-1, all runs	0.0072	0.0030	0.421
Channel 3-2, all runs	0.0352	0.0111	0.316
Site 3, all runs	0.0212	0.0170	0.801
Bluegate, all runs	0.0215	0.0073	0.338
Mancos Und., all runs	0.0192	0.0144	0.747
All Mancos, all runs	0.0186	0.0124	0.665
Non-Mancos (Site 8)	0.0047	-	-

In order to determine the extent to which the salt-sediment relationship applies, data collected by Ponce (1975) were analyzed and then summarized by geologic type in table 16. The values presented represent the mean and standard deviation of the ratio of total dissolved solids to suspended solids concentration of the composite sample from each plot on a given geologic type. Since the conversion of both TDS and SS from a concentration to a weight would be accomplished by multiplying both the numerator and denominator by the same number (total runoff volume), this step was bypassed. The fact that only one point was utilized from each plot could have contributed to the high coefficients of variation.

Table 16. Salt-sediment ratios resulting from overland flow on soil of various geologic origins in the Price River basin (from Ponce, 1975)

Geologic Type (Formation)	Mean Salt-Sediment Ratio	Standard Deviation	Coefficient of Variation
Alluvial Deposits	0.256	0.232	0.906
Black Hawk	0.016	0.007	0.438
Cedar Mountain	0.033	0.029	0.879
Colton	0.009	0.003	0.333
Gravel Caps	0.032	0.017	0.531
Green River	0.011	0.004	0.364
Mancos Shale			
Upper Bluegate	0.015	0.011	0.733
Middle Bluegate	0.019	0.011	0.579
Lower Bluegate	0.027	0.021	0.778
Musuk	0.015	0.006	0.400
Tununk	0.053	0.043	0.811
Mancos Undivided	0.063	0.038	0.603
North Horn	0.009	0.005	0.556
Price River	0.005	0.002	0.400

Note that, with only few exceptions, the salt-sediment ratios resulting from overland flow also tend to range between one and five percent. Similar results were found in relation to major channel storm runoff events, using information provided by Mundorff (1972; see table 17). A comparison of TDS and SS as given by Mundorff for various major channels emphasized the fact that this phenomenon is valid only in relation to storms. This, however, creates no boundaries as far as micro-channels and overland flow are concerned since these receive input only during storm events.

Table 17. Salt-sediment ratios resulting from storm runoff events in major channels in the Price River basin (from Mundorff, 1972)

Map Number	Total Dissolved Solids Concentration, in milligrams per liter	Suspended Solids Concentration, in milligrams per liter	Salt-Sediment Ratio
31	2770	184,500	0.015
32	2620	130,000	0.020
37	2320	49,000	0.047
38	1020	22,700	0.045
46	1780	49,700	0.036
69	3550	78,800	0.045

Note: All samples collected on 29 August 1969

The applicability of the salt-sediment relationship on a practical basis is obvious. By predicting the suspended sediment load and choosing the correct B value, the salt load under natural and managed conditions can be determined. This approach is similar to that taken by McElroy et al. (1976) for predicting various sediment-related organic and inorganic pollutants. The drawback, as always, lies with accurately choosing the correct coefficients, both in terms of sediment yield prediction and the value for B.

In order to aid the land manager in judiciously selecting the correct B value, various channel parameters were graphically compared with the salt-sediment ratio. These parameters were limited to those factors which are measurable prior to an event to enhance the predictability of any resulting equations. Comparisons were made between B and the electrical conductivity of the one-to-one soil extract, the

average percent sand, the average percent silt, the average percent clay, and the average percent silt plus clay of the surface inch of the channel bottom as well as the average percent slope of the channel bottom. Various transformations and interactions were created using the basic data after studying the graphical comparisons. All of these data, transformations, and interactions were then entered into the upwards stepwise multiple regression program of the Department of Applied Statistics and Computer Science at Utah State University to determine the best model for predicting B at various locations throughout the basin. Using r^2 as the objective function to be maximized and a multicollinearity analysis (using a threshold r value of 0.30) to assure that correlation between independant variables was minimized, B was found to be expressed by equation (7).

$$B = -0.00143 + (1.63)\ (10^{-7})\ X_1X_2 + (7.12)\ (10^{-7})\ X_2^3 \qquad (7)$$

where B is a unitless number representing the slope of the linear regression line through the origin of a plot of accumulated sediment versus accumulated salt (i.e. the proportion of salt in a given stream of known sediment load); X_1 is the electrical conductivity, in μmhos/cm at 25°C, of the one-to-one extract of a composite of soil samples collected from the surface inch (25 mm) of the channel bottom; and X_2 is the average percent clay, as determined by the hydrometer method, of the surface inch (25 mm) of the channel bottom. For practical purposes it is assumed that X_2 could also be determined from the same composited sample used in evaluating X_1. The results of an F test showed that both variables (X_1X_2 and X_2^3) were significant contributors

to the equation at the 0.95 level. The r^2 and r values associated with equation (7) were, respectively, 0.479 and 0.692. Snedecor (1946) has shown that this value of the coefficient of correlation is significantly different from zero at the 0.99 level (21 degrees of freedom). The standard error of the estimate associated with the equation was found to be 0.0001. Figure 18 shows that, within the range of X_1 and X_2 measured in this study, equation (7) is much more sensitive to percent clay than to the EC of the 1:1 extract. This is as expected considering the cubic term in the equation and the relative sizes of the regression coefficients. It should be pointed out that lower limits to X_1 and X_2 exist in order to make equation (7) valid, as seen in figure 19. This results from the negative constant used in the calculation of B.

With the aforementioned relationships in mind a comparison of relative salt outputs from micro-channels and overland flow was made using channel 1-2 and micro-watersheds seven through nine studied by Ponce (1975). This area was chosen over others because the micro-watersheds drain directly into the channel whereas other channels were merely in the vicinity of various plots investigated by Ponce with no apparent direct hydrologic linkage. An analysis of the rainstorms simulated by Ponce at micro-watersheds seven through nine revealed that an average of 1.88 inches (48 mm) was sprinkled on the plots during the 30 minute study period as compared with an average required storm size of 0.75 inch (19 mm) to produce the flows of the same duration investigated at channel 1-2. In order to make an estimation of the

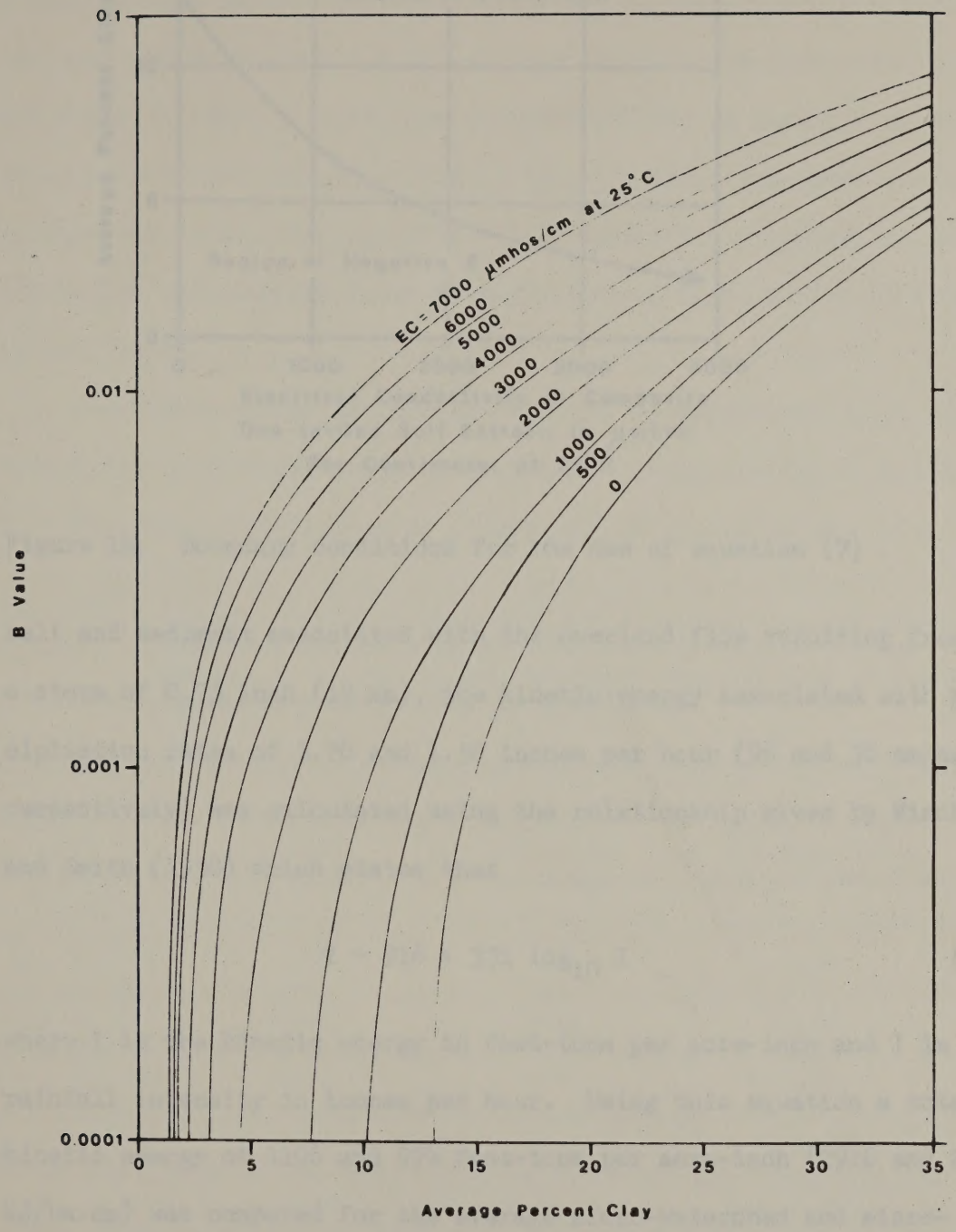


Figure 18. Effects on B of commonly measured values of average percent clay and electrical conductivity of the one-to-one soil extract of the channel bottom

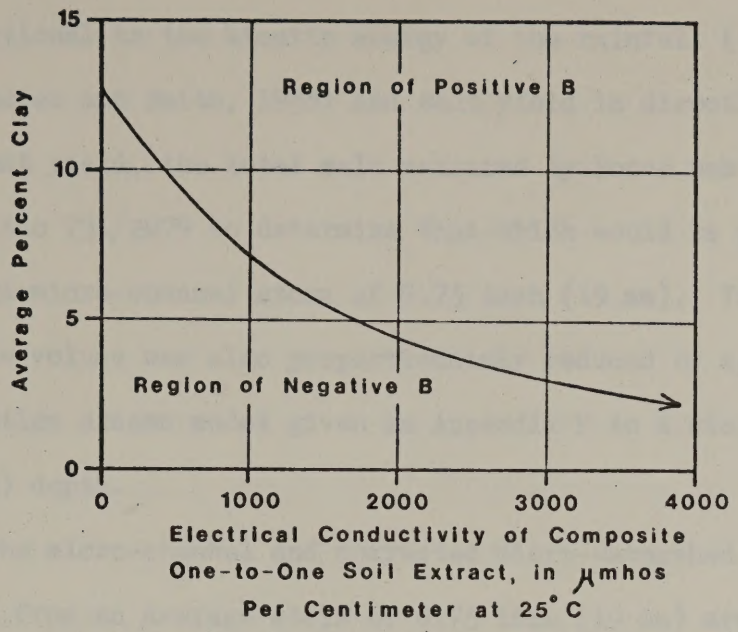


Figure 19. Boundary conditions for the use of equation (7)

salt and sediment associated with the overland flow resulting from a storm of 0.75 inch (19 mm), the kinetic energy associated with precipitation rates of 3.76 and 1.50 inches per hour (96 and 38 mm/hr, respectively) was calculated using the relationship given by Wischmeier and Smith (1958) which states that

$$Y = 916 + 331 \log_{10} I \qquad (8)$$

where Y is the kinetic energy in foot-tons per acre-inch and I is the rainfall intensity in inches per hour. Using this equation a total kinetic energy of 1106 and 974 foot-tons per acre-inch (2918 and 2569 kJ/ha·cm) was computed for the average micro-watershed and micro-channel storm, respectively. Converting these values from a volume to an area basis yields 2079 and 731 foot-tons per acre, respectively (13,934 and 4894 kJ/ha). Assuming that sediment production is directly

proportional to the kinetic energy of the rainfall (implied by Wischmeier and Smith, 1958) and salt yield is directly proportional to sediment yield, the total salt measured by Ponce was multiplied by the ratio 731/2079 to determine that which would be produced by the average micro-channel storm of 0.75 inch (19 mm). The total surface outflow volume was also proportionately reduced by applying the infiltration excess model given in Appendix F to a storm of 0.75 inch (19 mm) depth.

The micro-channel and corrected micro-watershed results of salt output from an average storm of 0.75 inch (19 mm) are given in table 18. Note that a micro-channel flow length of approximately 50 to 100

Table 18. Average 30 minute salt load and concentration for micro-watersheds seven through nine (from Ponce, 1975) and channel 1-2. Values are averaged over all runs and corrected for differences in storm sizes

Study area[a]	Average Flow Volume, in liters	Average Salt Load, in grams	Average Salt Concentration, in grams per liter
MW, 7-9	27	11.8	0.44
1-2, 10 ft	5775	644	0.11
1-2, 25 ft	5760	1153	0.20
1-2, 50 ft	5730	1748	0.31
1-2, 100 ft	5670	4176	0.74

[a] MW 7-9 refers to the micro-watersheds of corresponding numbers studied by Ponce (1975). 1-2, 10 ft refers to the 10 foot station of channel 1-2, and so forth. 1 foot = 0.305 m

feet (15 to 30 m) is required before a salt and sediment concentration equal to that of the inflowing surface runoff is reached. Dilution is undoubtedly the reason that a longer channel-associated flow length is required, relative to surface runoff, to reach a given concentration (each micro-watershed was approximately 10 feet or 3 m long). Because plot length studies by Ponce (1975) were inconclusive, it is difficult to determine whether or not increased overland flow distances would have an appreciable effect on salt concentrations and loads.

A glance at table 13 reveals that run number two in channel 1-2 compared closely with the average conditions of said channel as presented in table 18 (average 30 minute salt concentration of 0.74 grams per liter at the 100 foot or 30 m station). From figure 14 it is apparent that a distance-related equilibrium TDS concentration of approximately 2.95 grams per liter was realized during the indicated run in channel 1-2. This represents a seven-fold increase in concentration over that contributed by overland flow (2.95/0.42). Thus, during the course of a natural event of depth 0.75 inch (19 mm), each 40 square foot (3.7 m^2) area (the approximate size of each micro-watershed) above the inlet flume of channel 1-2 could be expected to yield 27 liters of water and 11.8 grams of salt to the channel. As a result of the convergence of the yields from each of the 207 micro-watershed sized plots within the drainage area of the channel (total drainage area equals 8280 square feet or 770 m^2), a total of 5790 liters of water and 2440 grams of salt is delivered to the channel (with a concentration of 0.44 grams per liter). As this block of water moves downstream an increased amount of salt is picked up until the concentration at the 1000 foot (300 m) mark is approximately 3.39 grams per liter (2.95 +

0.44). Assuming only negligible losses of water due to infiltration and evaporation, it is estimated that a salt load of approximately 21,000 grams would be delivered to the 1000 foot (300 m) point.

The reason for the higher salt loads resulting from channel processes is obvious. Salt and associated sediment pickup from overland flow is accomplished with only small amounts of energy available from raindrop impact and sheet flow. Channel runoff, however, can dissipate much more energy because of turbulence and greater depth (head), thus resulting in more pickup. Because it is suspected that the mechanisms which govern sediment yield also, to a large extent, control salt production in the Price River basin, the seven-fold increase in salt concentrations in micro-channels relative to surface runoff events is assumed to be a basin wide phenomenon. It is also theorized that salt loads resulting from micro-channel flows are increased by a factor of seven to ten over that entering the channel via overland flow, the exact amount depending upon the volume of water lost to seepage during an event.

Because of the significant correlation between salt and sediment in the basin, it was felt that the annual contribution of micro-channels to the salt load of the Price River could best be estimated by first determining the sediment yield from the same source. A review of the literature, however, revealed that annual sediment yield prediction equations which incorporate channels as a source are nonexistent with the exception of preliminary work presented by Renard et al. (1974). Because the study was still in the reconnaissance stage, however, the use of this method was not deemed proper.

The reviewed literature also produced little in the way of on-site measurements of sediment yields from micro-channels. Of significance, though, were the results presented by Thomas (1975), who found that gully plugs in the Cisco Basin area of eastern Utah were successful in trapping an average of 1.99 tons per acre (4.45 metric tons per hectare) of sediment annually. Because of the similarities between the two basins, it is assumed that micro-channels in the Price River basin produce sediment at the same rate measured by Thomas. As Mundorff (1972) pointed out, the non-Mancos highlands of the basin yield little sediment and thus the quoted sediment yield values are assumed to be indicative of Mancos shale lands with insignificant quantities of sediment being produced elsewhere in the basin. It should be noted that the value of 1.99 tons per acre per year (4.45 MT/ha/yr) compares favorably with the estimated annual sediment yields of 2.19 tons per acre (4.9 MT/ha) reported by Mundorff (1972) for the entire Price River basin and 2.81 tons per acre (6.3 MT/ha) reported by Todd (1970) for the Upper Colorado River basin.

Utilizing the aforementioned assumptions and the B values for the various geologic types presented in tables 14 and 15, the results presented in table 19 were computed. This table shows that 9791 tons (8883 MT) of salt can be expected to be yielded by micro-channels within the basin each year. According to the U.S. Geological Survey (1974), the average annual discharge of the Price River at Woodside is 73,900 acre-feet (1230 m^3). Using the available water quality records from 1965 through 1973, an average annual total dissolved solids discharge of 3.90 tons per acre-foot (125 MT/m^3) was computed for the same station.

Table 19. Estimated annual sediment and salt yields from Mancos shale lands in the Price River basin due to micro-channels

Mancos Shale Member	Percent of Basin Covered	Coverage Area, in acres (hectares)	Estimated Annual Sediment yield, in tons (metric tons)	Estimated Annual Salt Yield, in tons (metric tons)
Masuk	4.40	53,150 (21,510)	105,520 (95,730)	316 (287)
Bluegate	9.29	112,240 (45,420)	222,800 (202,120)	4789 (4345)
Tununk	1.21	14,630 (5,920)	29,020 (26,330)	82 (74)
Undivided Mancos	10.00	120,810 (48,890)	239,810 (217,560)	4604 (4177)

This results in 288,210 tons (153,750 MT) of salt flowing past the Woodside station annually. The estimated contribution from micro-channels makes up only 3.4 percent of this total. It will be recalled that the production of salt from micro-channels was estimated to be approximately seven to ten times that resulting from surface runoff. Note that 3.4 percent is approximately seven times greater than 0.5 percent, the percentage of salt at Woodside attributed by Ponce (1975) to overland flow. It must be remembered that the values presented in relation to micro-channel salt contributions to the Price River are only estimates. These estimates were made using a limited amount of data collected from sites scattered throughout a highly heterogeneous basin. The simplifying assumption was further made that average gully erosion rates measured at two sites in the nearby Cisco basin are typical of the Mancos lands of the Price River basin. However, even

if an underestimation on the order of 200 or 300 percent has been made, it appears that national resource lands contribute a much smaller amount to the salinity of the Price River than had previously been suspected.

CONCLUSIONS

1. The salinity of micro-channel systems is inherently extremely variable. This variability tends to increase with increasing salt content of the system.

2. Within a specific channel bank, the concentration and spatial variability of salts tend to increase with increasing depth. This suggests that in situ weathering of the channel banks is proceeding at a faster rate than mass wasting.

3. Seepage during an event in channels with bottoms high in silt and clay is generally minimal. Inflow and outflow differ greatly where the channel bottom consists of exposed shale beds or a high percentage of sand.

4. The flows utilized during the study can be expected to occur naturally under rather common circumstances.

5. On the average, approximately one-half inch (13 mm) of soil was removed from the channel bottom as a result of scour during each run throughout the basin.

6. The Bluegate member of the Mancos shale is the prime source of salt within the basin.

7. Calcium sulfate (gypsum) is the main salt encountered in the basin with sodium being the most common monovalent cation.

8. A good linear correlation exists between electrical conductivity and total dissolved solids, suspended solids and total dissolved solids, as well as electrical conductivity and suspended solids. This correlation is most significant in more saline systems.

9. Electrical conductivity is a significant index of ionic species concentrations within the basin.

10. During the course of an event, suspended solids and total dissolved solids concentrations increase with distance downstream and decrease with time, the latter also being a phenomenon noted in relation to overland flow (Ponce, 1975).

11. Approximately 20 or 25 minutes after the beginning of a runoff event, both total dissolved solids and suspended solids can be expected to have reached a state of quasiequilibrium. This apparently is the time required for the loose, easily eroded material on the surface of the channel to be washed away, suggesting the inherent chemical and physical properties of the soil thereafter become dominate in the salt and sediment release process.

12. Of the models tested, salt release (concentration versus time) within the basin is best described by a linear model of total dissolved solids versus the square root of time, meaning that salt release is a diffusion controlled process.

13. A flow distance of approximately 800 or 1000 feet (240 or 300 m) is required before the total dissolved solids concentration of the flow reaches a distance-related quasiequilibrium. The exact distance is probably dependant upon the degree of chemical saturation of the water and the salt content of the channel.

14. The effects of an event on the salt and sediment output of subsequent events is not fully understood.

15. On the average, bedload accounted for approximately 40 percent of the total sediment measured during all runs throughout the basin.

16. Salt loads are relatively insensitive to variations in flow parameters. Channel factors have a somewhat greater influence on salt

production but the linear relationship is still somewhat marginal.

17. Sediment load is a significant index of salt load within the basin. The fact that salt and sediment are highly correlated should not imply that all salt produced is inherently associated with the sediment but rather that the same processes whereby sediment is produced also result in the release of salt.

18. The salt-sediment regression line slope (B) generally increases from run to run indicating that the output of salt is increasing slightly relative to sediment.

19. The ratio of salt to sediment increases with time at a given point in the channel during the course of an event. Thus, the rate of sediment pickup decreases at a faster rate than the salt pickup rate. The ratio also decreases with distance downstream due to the presence of more sediment in the stream with increasing flow length. Neither phenomenon (increase with time or decrease with distance) appears to play an important role where flow distances are greater than 50 feet (15 m).

20. A comparison of overland flow, micro-channel, and major channel storm runoff events showed that the salt sediment ratio generally falls between one and five percent throughout the basin, regardless of the point of measurement. This relationship is no longer important in major channels during non-storm periods.

21. B can best be predicted by a multiple regression equation involving the electrical conductivity of the composite 1:1 extract and the average percent clay of the channel bottom. This equation, is more sensitive to measurements of percent clay than EC within the range of values measured in this study.

22. A micro-channel flow length of approximately 50 to 100 feet (15 to 30 m) is required before a salt concentration equal to that of the inflowing surface runoff is reached. By the time a state of quasiequilibrium is reached in relation to salt concentration, a seven-fold increase in the concentration of salts due to micro-channels has occured relative to overland flow.

23. Salt loads are increased seven to ten times between overland flow and micro-channel runoff events.

24. Micro-channels contribute approximately 3.4 percent of the total salt load of the Price River at Woodside. Coupled with the contribution of overland flow (Ponce, 1975) it appears that national resource lands within the basin contribute less to the salinity of the Price River than had previously been suspected.

RECOMMENDATIONS FOR FURTHER RESEARCH

As a result of this study, a few possibilities for future research have surfaced and should be presented:

1. As was mentioned in the text, the need exists for practical methodologies for predicting sediment yields from ephemeral channels on an annual basis. Studies in the past seem to have dealt either with sediment yields resulting from overland flow or that being deposited in the reservoir at the lower end of a particular drainage basin with little attention being paid to the processes in between. Because sediment plays such a vital role in water resource planning, it is essential that its yield in relation to channels be better understood.

2. Because of the low estimated contributions of diffuse sources to the salinity of the Price River, it is recommended that an intense salt budget study of the basin be carried out. This would include the quantification of dissolved solids loads and concentrations from diffuse sources (both surface and subsurface), irrigation return flows, municipal discharges, and concentrating effects due to stream diversions. The results of such an intensive study would either validate or invalidate the findings of the current study and Ponce (1975), thereby pinpointing the problem areas and making management efforts more efficient. A study such as this would also allow estimates of background salinity to be made.

3. Studies of the salt-sediment relationship should be expanded to determine the applicability of equation (7) in areas other than the

Price River basin. Similar equations could be developed for overland flow and major channel events to determine, in a broader sense, the total contribution of diffuse sources to the Colorado River system during storm events.

4. Regardless of the difficulties involved, it is necessary that field studies be carried out using natural inputs. This would give more validity to the results of the study.

LITERATURE CITED

Agricultural Research Service. 1962. Field Manual for Research in Agricultural Hydrology. USDA Agricultural Handbook No. 224. US Government Printing Office. Washington, D.C.

American Public Health Association. 1971. Standard Methods for the Examination of Water and Wastewater, 13th ed. American Public Health Association. Washington, D.C.

Beer, C.E. and H.P. Johnson. 1963. Factors in Gully Growth in the Deep Loess Area of Western Iowa. Transactions of ASAE. 6(3):237-240.

Blackman, W.C., Jr., J.V. Rouse, G.R. Schillinger, and W.H. Schafer, Jr. 1973. Mineral Pollution in the Colorado River Basin. Journal of Water Pollution Control Federation. 45(7):1517-1557.

Bower, C.A. and L.V. Wilcox. 1965. Soluble Salts. In C.A. Black, ed. Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. American Society of Agronomy, Inc. Madison, Wisconsin.

Cannon, H.L. 1960. The Development of Botanical Methods of Prospecting for Uranium on the Colorado Plateau, US Geological Survey Bulletin 1085-A. US Government Printing Office. Washington, D.C.

Cordova, R.M. 1964. Hydrogeologic Reconnaissance of Part of the Headwaters Area of the Price River, Utah. Utah Geological and Mineralogical Survey Water Resources Bulletin No. 4.

Davis, R.E. 1950. Surveying. In L.C. Urqahart, ed. Civil Engineering Handbook, 3rd ed. McGraw-Hill Book Co., Inc. New York.

Dunn, O.J. and V.A. Clark. 1974. Applied Statistics: Analysis of Regression and Variance. John Wiley and Sons, Inc. New York.

Garrels, R.M. and C.L. Christ. 1965. Solutions, Minerals, and Equilibria. Harper and Row Publishers. New York.

Hamilton, T.M. 1970. Channel-scarp Formation in Western North Dakota. US Geological Survey Professional Paper 700-C. US Government Printing Office. Washington, D.C. p C229-C232.

Hastings, J.R. 1959. Vegetation Change and Arroyo Cutting in Southeastern Arizona. Journal of the Arizona Academy of Science. 1(2):60-67.

Heede, B.H. 1967. The Fusion of Discontinuous Gullies - A Case Study. Bulletin of the International Association of Scientific Hydrology. 12(4):42-50.

Heede, B.H. 1971. Characteristics and Processes of Soil Piping in Gullies. USDA Forest Service Research Paper RM-68. Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colo.

Heede, B.H. 1975a. Stages of Development of Gullies in the West. In Present and Prospective Technology for Predicting Sediment Yields and Sources. USDA Agricultural Research Service. ARS-S-40. p 155-161.

Heede, B.H. 1975b. Mountain Watersheds and Dynamic Equilibrium. Presented at the August 1975 ASCE Watershed Management Symposium. Logan, Utah. p. 407-420.

Heede, B.H. 1976. Gully Development and Control: The Status of Our Knowledge. USDA Forest Service Research Paper RM-169. Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colo.

Hunt, C.B. 1956. Cenezoic Geology of the Colorado Plateau. US Geological Survey Professional Paper 279. US Government Printing Office. Washington, D.C.

Jeppson, R.W., G.L. Ashcroft, A.L. Huber, G.V. Skogerboe, and J.M. Bagley. 1968. Hydrologic Atlas of Utah. Utah Water Research Laboratory and State of Utah Department of Natural Resources. PRWG35-1. Utah State University. Logan, Utah.

Kuichling, E. 1889. The Relation Between the Rainfall and the Discharge of Sewers in Populous Districts. Transactions of ASCE. 20:1-56.

Leopold, L.B. and J.P. Miller. 1956. Ephemeral Streams - Hydraulic Factors and Their Relation to the Drainage Net. US Geological Survey Professional Paper 282-A. US Government Printing Office. Washington, D.C.

Leopold, C.B., M.G. Wolman, and J.P. Miller. 1964. Fluvial Processes in Geomorphology. W.H. Freeman and Co. San Francisco.

Lupton, C.T. 1916. Geology and Coal Resources of Castle Valley in Carbon, Emery, and Sevier Counties, Utah. US Geological Survey Bulletin 628. US Government Printing Office. Washington, D.C.

Mc Elroy, A.D., S.Y. Chiu, J.W. Nebgen, A. Aleti, and F.W. Bennett. 1976. Loading Functions for Assessment of Water Pollution from Nonpoint Sources. Environmental Protection Technology Series Report No. EPA-600/2-76-151 prepared by the Midwestern Research Institute. US Environmental Protection Agency. Washington, D.C.

Miller, C.R., R. Woodburn, and H.R. Turner. 1962. Upland Gully Sediment Production. Symp. of Bari, Comm. of Land Erosion. International Association of Scientific Hydrology Publication No. 59. p 83-104.

Mundorff, J.C. 1972. Reconnaissance of Chemical Quality of Surface Water and Fluvial Sediment in the Price River Basin, Utah. Utah Department of Natural Resources, Division of Water Rights. Technical Publication No. 39. Salt Lake City.

Office of Public Services. 1962. U.S. and Mexico to Study Salinity of Colorado River Water. The Department of State Bulletin. Bureau of Public Affairs. Press Release 900 Date December 21. 46(1178):144.

Office of Public Services. 1972. U.S. and Mexico Approve Agreement of Colorado River Water Quality. The Department of State Bulletin. Bureau of Public Affairs. Department of State press release 177 dated July 17. 67(1729):197-199.

Office of Public Services. 1975. United States and Mexico Reach Agreement on Colorado River Salinity Problem. The Department of State Bulletin. Bureau of Public Affairs. 69(1787):388-396.

Orion Research, Inc. 1976. Instruction Manual: Model 801-A (Digital pH/mv Meter). Cambridge, Mass.

Orme, A.R. and R.G. Bailey. 1970. The Effect of Vegetation Conversion and Flood Discharge on Stream Channel Geometry: The Case of Southern California Watersheds. Association of American Geographers Proceedings. Vol 2. p 101-106.

Patton, P.C. and S.A. Schumm. 1975. Gully Erosion, Northwestern Colorado: A Threshold Phenomenon. Geology. 3(2):88-90.

Perkin-Elmer Corp. 1973. Analytical Methods for Atomic Absorption Spectrophotometry. Norwalk, Conn.

Ponce, S.L., II. 1975. Examination of a Non-point Source Loading Function for the Mancos Shale Wildlands of the Price River Basin, Utah. Dissertation presented to Utah State University, at Logan, Utah, in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Civil and Environmental Engineering.

Ponce, S.L., II, R.H. Hawkins, J.J. Jurinak, G.F. Gifford, and J.P. Riley. 1975. Surface Runoff and its Effects on Diffuse Salt Production from Mancos Shale Members. Presented at the August 1975 ASCE Watershed Management Symposium. Logan, Utah. p 140-168.

Renard, K.G., J.R. Simanton, and H.B. Osborn. 1974. Applicability of the Universal Soil Loss Equation to Semiarid Rangeland Conditions in the Southwest. Presented at the April 1974 meetings of the Arizona Section of the American Water Resources Association and the Hydrology Section of the Arizona Academy of Science. Flagstaff, Arizona. p 18-32.

Richardson, E.A. 1971. Estimated Return Periods for Short-duration Precipitation in Utah. Department of Soils and Biometeorology Bulletin No. 1. Utah State University. Logan, Utah.

Schumm, S.A. 1960. The Shape of Alluvial Channels in Relation to Sediment Type. US Geological Survey Professional Paper 352-B. US Government Printing Office. Washington, D.C. p 16-30.

Schumm, S.A. and R.F. Hadley. 1957. Arroyos and the Semiarid Cycle of Erosion. American Journal of Science. 255:161-174.

Seginer, I. 1966. Gully Development and Sediment Yield. Journal of Hydrology. 4(3):236-253.

Shantz, H.L. and R. Zon. 1924. Natural Vegetation. In O.E. Baker, ed. Atlas of American Agriculture (published in 1936). US Government Printing Office. Washington, D.C.

Snedecor, G.W. 1946. Statistical Methods. The Iowa State College Press. Ames, Iowa.

Soil Conservation Service. 1972. SCS National Engineering Handbook Section 4: Hydrology. US Government Printing Office. Washington, D.C.

Spiegel, M.R. 1961. Schaum's Outline of Theory and Problems of Statistics. McGraw-Hill Book Company. New York.

Stokes. W.L. 1944. Morrison Formation and Related Deposits in and Adjacent to the Colorado Plateau. Bulletin of the Geological Society of America. 55:951-992.

Stokes. W.L. (ed.). 1964. Geologic Map of Utah. University of Utah. Salt Lake City.

Stokes, W.L. and R.E. Cohenour. 1956. Geologic Atlas of Utah: Emery County. Utah Geological and Mineralogical Survey Bulletin 52.

Stumm, W. and J.J. Morgan. 1970. Aquatic Chemistry: An Introduction Emphasizing Chemical Equilibria in Natural Waters. Wiley-Interscience. New York.

Swenson. J.L., Jr., D.T. Erickson, K.M. Donaldson, and J.J. Shiozaki. 1970. Soil Survey of Carbon-Emery Area, Utah. USDA Soil Conservation Service. US Government Printing Office. Washington, D.C.

Tanji, K.K. 1969. Solubility of Gypsum in Aqueous Electrolytes as Affected by Ion Association and Ionic Strengths up to 0.15 M at 25°C. Environmental Science and Technology. 3(7):656-661.

Thomas, D.B. 1975. The Effects of Gully Plugs and Contour Furrows on Erosion and Sedimentation in Cisco Basin, Utah. Thesis Presented to Utah State University, at Logan, Utah, in partial fulfillment of the requirements for the degree of Master of Science in Range Science.

Thompson, J.R. 1964. Quantitative Effect of Watershed Variables on Rate of Gully-head Advancement. Transactions of ASAE. 7(1):54-55.

Thorne, J.P., L. Wilson, T.B. Hutchings, and J. Swenson. 1967. Chemical and Physical Properties of Soils in the Carbon-Emery Area, Utah. Utah Agricultural Experiment Station, Utah. Resources Series 39. Utah State University. Logan, Utah.

Todd, D.K., ed. 1970. The Water Encyclopedia. Water Information Center. Port Washington, New York.

US Bureau of the Census. 1913. Census of the United States: 1910 (vol. III, Population: Nebraska-Wyoming). US Government Printing Office. Washington, D.C.

US Bureau of the Census. 1922. Census of the United States: 1920 (vol. III, Composition and Characteristics of the Population by States). US Government Printing Office. Washington, D.C.

US Bureau of the Census. 1932. Census of the United States: 1930 (vol. III, part 2, Population: Montana-Wyoming). US Government Printing Office. Washington, D.C.

US Bureau of the Census. 1943. Census of the United States: 1940 (vol. II, part 7, Population: Utah-Wyoming). US Government Printing Office. Washington, D.C.

US Bureau of the Census. 1952. U.S. Census of Population: 1960 (vol. I, part 46, Characteristics of the Population: Utah). US Government Printing Office. Washington, D.C.

US Bureau of the Census. 1973. Census of the Population: 1970 (vol. I, part 46, Characteristics of the Population: Utah). US Government Printing Office. Washington, D.C.

US Environmental Protection Agency. 1971. The Mineral Quality Problem in the Colorado River Basin, Appendix A: Natural and Man-made Conditions Affecting Mineral Quality. US Government Printing Office. Washington, D.C.

US Geological Survey. 1974. Water Resources Data for Utah, Part I: Surface Water Records. Water Resources Division. Salt Lake City.

Utah Division of Water Resources. 1975. Hydrologic Inventory of the Price River Basin. Utah Department of Natural Resources. Salt Lake City.

Utah Water Research Laboratory. 1975. Colorado River Regional Assessment Study, Part I: Executive Summary, Basin Profile, and Report Digest. Utah State University. Logan, Utah

Whitmore, J.C. 1976. Some Aspects of the Salinity of Mancos Shale and Mancos Derived Soils. Thesis presented to Utah State University, at Logan, Utah, in partial fulfillment of the requirements for the degree of Master of Science in Soil Science.

Wischmeier, W.H. and D.D. Smith. 1958. Rainfall Energy and Its Relationship to Soil Loss. Transactions of the American Geophysical Union. 39(2):285-291.

Youngs, F.O. and D.S. Jennings. 1939. Soil Survey of the Price Area, Utah. USDA Bureau of Chemistry and Soils. Series 1934, no. 13. US Government Printing Office. Washington, D.C.

Zimmerman, R.C., J.C. Goodlett, and G.H. Comer. 1967. The Influence of Vegetation of Channel Form of Small Streams. International Association of Scientific Hydrology Publication 75. p 255-275.

APPENDIXES

APPENDIX A

Description of Micro-channel Study Sites

The following sites and channels were chosen for the study of salt production from micro-channels in the Price River basin, Utah. The micro-watersheds and infiltrometer plots mentioned are those studied by Ponce (1975).

Site 1

In SE¼ sec. 21, T.15S., R.9E. Approximately 100 feet (30 m) west of state highway 50 in the southwest corner of the section. The site is found on USGS topographic map, Castle Gate Quadrangle (1914, 15 minute series) on the Bluegate member of the Mancos shale. It is located in the same area as the previously studied micro-watersheds 7 - 9 and infiltrometer plot 5. Vegetation is sparse and consists primarily of Indian Rice grass, Salina wild-rye, mat saltbush, shadscale, and various small shrubs. Approximate elevation is 6100 feet (1860 m) above msl.

Channel 1-1: 125 feet (40 m) northwest of micro-watersheds 7 - 9. The channel is 100 feet (30 m) long with a channel bottom ranging in width from 0.5 to 1.0 foot (15 to 30 cm). The channel has steep sideslopes (approximately 100 percent) and fairly uniform slope of about 7 percent.

Channel 1-2: Directly below micro-watersheds 7 - 9. The channel is approximately 100 feet (30 m) long with a bottom ranging from 0.5 to 1.5 feet (15 to 45 cm) wide. The upper 50 feet (15 m) of the channel is fairly flat while the lower 50 feet (15 m) is of a steeper gradient (approximately 8-10%). Steep sideslopes dominate (100 to 150 percent). Some mass wasting has occured.

Channel 1-3: 175 feet (55 m) west of channel 1-1. The test section is approximately 100 feet (30 m) long with a bottom width which ranges from 0.5 to 1.0 foot (15 to 30 cm). Sideslopes are moderately steep (about 60 percent). The channel slope is approximately 10% in the upper half and slightly more gentle in the lower half of the test section.

Site 2

In NW¼ sec. 10, T.14S., R.11E. (east of road and west of Coal Creek). The site is located 6 miles (10 km) from the junction of "Coal Creek Road" and U.S. Highway 6-50. It is found on USGS topographic map, Deadman's Canyon Quadrangle (1972, 7.5 minute series), on Mancos Undivided upstream from infiltrometer plot 13. Vegetation is sparse to moderately sparse, consisting mainly of mat saltbush, rabbit brush, shadscale, and a few scattered grasses. Approximate elevation is 5760 feet (1755 m) above msl.

Channel 2-1: Located approximately 150 feet (45 m) east of the road. The channel is about 100 feet (30 m) long with a bottom width ranging from 8 inches to one foot (20 to 30 cm). Sideslopes have a gradient of approximately 75 percent. The overall channel gradient is gentle (about 3 percent) and uniform throughout.

Channel 2-2: Located about 300 feet (90 m) south of channel 2-1, and 100 feet (30 m) east of the road. The channel is 100 feet (30 m) long with moderately steep sideslopes (60 percent), a bottom width of about one foot (30 cm), and a uniform gentle gradient of about 3 percent.

Channel 2-3: Located about 10 feet (3 m) east of channel 2-2. The channel is approximately 100 feet (30 m) long with a bottom width

ranging from 6 to 8 inches (15 to 20 cm). Sideslopes have about a 60 percent slope. The overall channel gradient is uniform and approximately 5 percent.

Site 3

In SE¼, SW¼, sec. 31, T.15S. R.13E. The site is located northwest of the State Road Commission gravel mounds, approximately 350 yards (320 m) northwest of micro-watersheds 1-6 and infiltrometer plot 14. It is found on USGS topographic map, Mounds Quadrangle (1969, 7.5 minute series) on Undivided Mancos. Vegetation is moderately sparse and consists primarily of rabbit brush, greasewood, shadscale, salina wild-rye, and big sagebrush. Approximate elevation is 5360 feet (1630 m) above msl.

Channel 3-1: Located 200 yards (180 m) northwest of the State Road Commission gravel mounds, approximately 100 yards (90 m) west of the power lines. The channel gradient is uniform and gentle (about 5 percent) with a sideslope gradient of approximately 100 percent.

Channel 3-2: Located 100 yards (90 m) northwest of channel 3-1. The channel is 100 feet (30 m) long with a uniform, gentle gradient of about 3 percent. The sideslopes are moderately steep (about 60 percent). The channel bottom is about 1.0 foot (30 cm) wide throughout.

Channel 3-3: 100 feet (30 m) northwest of channel 3-2. The test section is about 100 feet (30 m) long. The channel bottom has a moderately gentle, uniform slope with a width ranging from 8 inches to one foot (20 to 30 cm). Sideslopes are moderately steep.

Site 4

In NW¼, SW¼, sec. 21, T.13S., R.10E., 3.4 miles (5.5 km) up State

Highway 157 towards Kenilworth, located on USGS topographic map, Castle Gate Quadrangle (1914, 15 minute series) on the Masuk member of the Mancos shale near infiltrometer plot 1. Vegetation is moderately dense and consists mainly of big sagebrush, rabbit brush, salina wild-rye, and indian rice grass with a few scattered Utah juniper and pinyon pine. Approximate elevation is 6350 feet (1935 m) above msl.

Channel 4-1: Located approximately 200 feet (60 m) south of Highway 157. The channel is shallow with an overall slope of about 5.5 percent and a bottom width ranging from 8 to 12 inches (20 to 30 cm). The test section is 200 feet (60 m) long.

Site 5

In NW¼, sec. 28, T.15S., R.10E., approximately 2 miles (3 km) east of State Highway 10 and 0.3 miles (0.5 km) northwest of infiltrometer plot 7. Located on USGS topographic map, Elmo Quadrangle (1969, 7.5 minute series) on the Bluegate member of the Mancos shale. Vegetation is moderately sparse and consists primarily of shadscale and salina wild-rye. Approximate elevation is 5680 feet (1730 m) above msl.

Channel 5-1: Located approximately 150 feet (45 m) northeast of road. The test section is 300 feet (90 m) long. The channel has moderately steep sideslopes (60 percent) of loose material with a bottom width of about 12 inches (30 cm). The overall channel slope in the test section is about 3.5 percent.

Site 6

In NE¼, SE¼, sec. 15, T.17S., R.10E., near infiltrometer plot 8 on the Bluegate member of the Mancos shale. Located on USGS topographic

map, Cleveland Quadrangle (1969, 7.5 minute series). Vegetation is moderately sparse, consisting of shadscale, salina wild-rye, and rabbit brush. Approximate elevation is 5720 feet (1740 m) above msl.

Channel 6-1: Located approximately 200 feet (60 m) west of the Cleveland-Lloyd Dinosaur Quarry road. The test section is 100 feet (30 m) long. The channel bottom contains numerous small outcrops of shale and has a width of 8 to 12 inches (20 to 30 cm) with nearly vertical sideslopes. The channel slope is approximately 5.5 percent.

Site 7

In $SE\frac{1}{4}$, $SE\frac{1}{2}$, sec. 14, T.17S., R.10E., near infiltrometer plot 12 on the Tununk member of the Mancos shale (directly below an outcrop of the Ferron Sandstone member of the Mancos shale). Located on USGS topographic map, Cleveland Quadrangle (1969, 7.5 minute series). Sparse vegetation exists and consists primarily of shadscale and salina wild-rye. Approximate elevation is 5640 feet (1720 m) above msl.

Channel 7-1: Located approximately 100 feet (30 m) south of the Cleveland-Lloyd Dinosaur Quarry road with a test section 100 feet (30 m) long. The channel bottom is 8 to 12 inches (20 to 30 cm) wide with an overall slope of about 2.5 percent. Sideslopes are steep (about 150 percent).

Site 8

In $NE\frac{1}{4}$, $SE\frac{1}{4}$, sec. 29, T.17S., R.11E., between infiltrometer plots 16 and 17 on the Cedar Mountain Formation. Located on USGS topographic map Cow Flats Quadrangle (1969, 7.5 minute series). Vegetation is moderately sparse and consists of shadscale, salina wild-rye, blue grama, and rabbit brush with a few scattered Utah juniper. Approximate

elevation is 5800 feet (1770 m) above msl.

Channel 8-1: Located approximately 50 feet (15 m) south of the Cleveland-Lloyd Dinosaur Quarry road. The test section is 100 feet (30 m) long. The channel bottom is one to two feet (30 to 60 cm) wide with an overall slope of about 4 percent. Sideslopes are gentle (20 to 40 percent). Many short tributaries (approximately 10 feet or 3 m long) enter the channel in the test section.

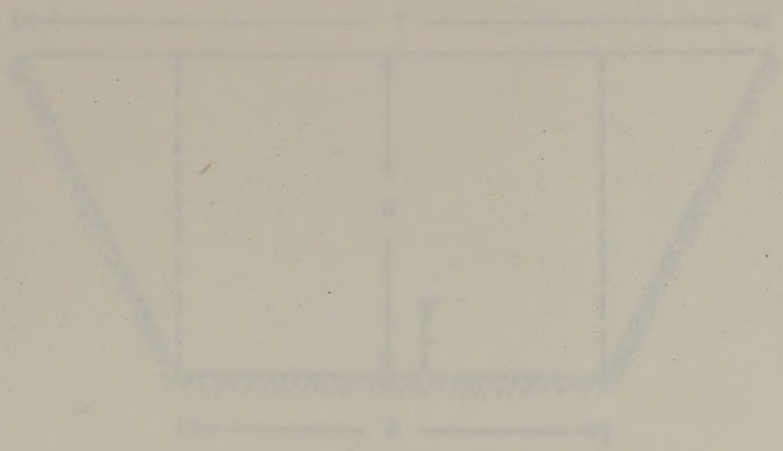
APPENDIX B

Methods Used for the Analysis of Water Samples and One-To-One Soil Extracts

The following methods were used for the analysis of water samples and 1:1 soil extracts collected during the micro-channel study, 1976:

Analysis	Method	Reference
HCO_3^-	Calculation	Garrels and Christ (1965), Stumm and Morgan (1970)
CO_3^{2-}	Calculation	Garrels and Christ (1965), Stumm and Morgan (1970)
SO_4^{2-}	Gravimetric	American Public Health Assoc. (1971)
Cl^-	Potentiometric using standards	Orion Research Inc. (1976)
Ca^{2+}	AAS*	Perkin-Elmer Corp. (1973)
Mg^{2+}	AAS	Perkin-Elmer Corp. (1973)
Na^+	AAS	Perkin-Elmer Corp. (1973)
K^+	AAS	Perkin-Elmer Corp. (1973)
Li^+	AAS	Perkin-Elmer Corp. (1973)
Suspended solids	Drying at 103°C	American Public Health Assoc. (1971)
Total dissolved solids	Drying at 103°C	American Public Health Assoc. (1971)
pH	Glass electrode	American Public Health Assoc. (1971)

* Atomic absorption spectrophotometry



APPENDIX C

Flow Parameters as Determined
Using the Assumption of a Trapezoidal Channel

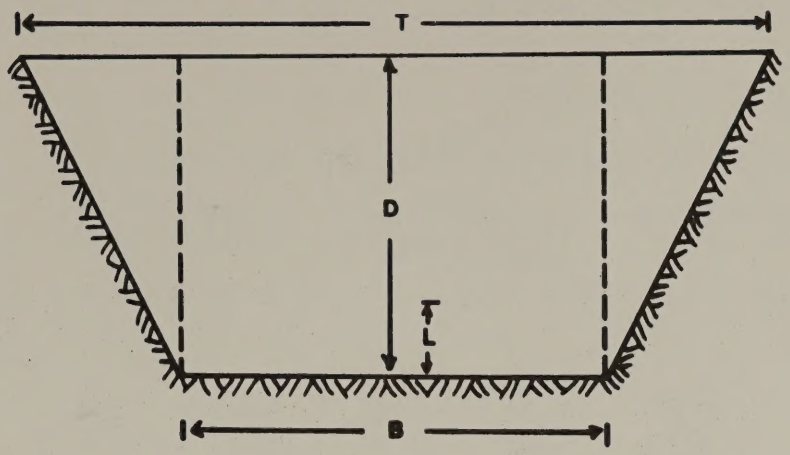


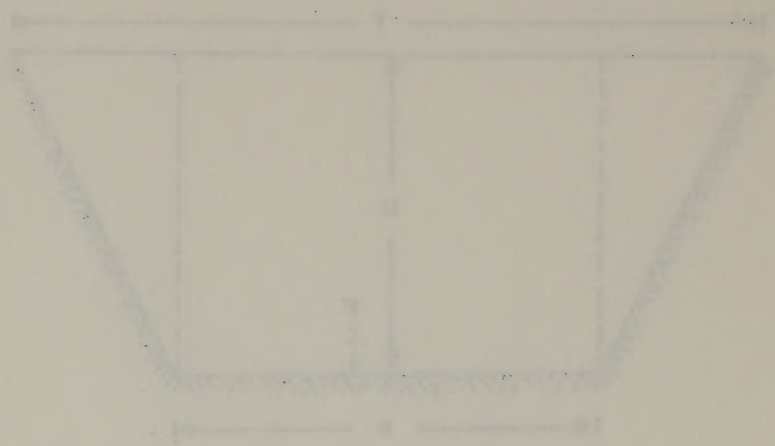
Figure 20. Measurements taken along the channel following each run for the determination of various flow parameters

In the above figure, T = the top width of the channel measured at the water level; B = the bottom width of the channel; D = the depth of flow; and L = the soil loss due to channel scouring. Using the assumption of a trapezoidal channel, the following parameters were computed by their respective equations:

$$\text{Cross sectional area, } A = BD + \left(\frac{T-B}{2}\right)(D) \tag{9}$$

$$\text{Wetted perimeter, } P = (2)\left[\left(\frac{T-B}{2}\right)^2 + D^2\right]^{\frac{1}{2}} + B \tag{10}$$

$$\text{Hydraulic radius, } R = \frac{A}{P} \tag{11}$$



APPENDIX D

Electrical Conductivity of One-To-One Soil Extracts of Samples Collected for the Channel Homogeneity Test

Table 20. Electrical conductivity in μmhos/cm at 25°C, of one-to-one extracts of samples collected for the channel homogeneity test. The locations given are when facing downstream. (Note: 1 foot = 0.305 m; 1 inch = 25 mm)

Distance Downstream, in feet	Location and Depth in Channel, in inches					
	Bottom		Left		Right	
	(0-1)	(1-6)	(0-1)	(1-6)	(0-1)	(1-6)
CHANNEL 1-3						
0	2130	2300	2210	2220	2140	2430
10	2070	2210	2200	2350	2230	2360
20	2090	2300	1500	2340	2140	2370
30	2080	2380	2250	2330	2200	2340
40	2040	2030	1800	2350	2320	2690
50	848	1030	2140	2260	2230	2410
60	1910	634	2250	2240	2110	2420
70	1230	1070	515	2270	2360	2680
80	1860	2060	235	227	2150	2330
90	1880	662	2230	2450	1630	2370
100	1080	2130	1200	2370	2270	2238
CHANNEL 2-3						
0	261	298	461	328	352	800
10	224	245	8110	5390	240	192
20	268	200	187	226	878	962
30	201	190	189	278	188	172
40	216	174	648	427	182	168
50	247	275	196	201	1140	3400
60	214	185	210	205	354	245
70	240	177	200	217	254	219
80	293	248	1110	2830	828	319
90	518	2310	460	2750	468	1540
100	374	755	1320	3590	216	220
CHANNEL 3-3						
0	3730	6250	5850	9680	17900	21900
10	6880	6730	10100	11500	12000	23600
20	11400	13500	11800	10600	28500	21400
30	3660	6660	3130	7820	21900	17500
40	10000	10320	19600	29400	13300	10500
50	9400	6705	20700	34100	17800	22200
60	8320	7440	22800	43700	15500	11300
70	2930	8210	26300	50000	5900	11700
80	2020	3100	3500	5570	9720	15750
90	2310	2540	11300	21100	2620	2530
100	1790	1140	2290	2480	669	692

APPENDIX E

Results of Size Fraction Analyses

of Selected Pre-run Soil Samples

Table 21. Results of size fraction analyses of selected pre-run soil samples

Channel	Run	Sample Station, in feet downstream	Percent Sand	Percent Silt	Percent Clay	Texture
1-1	1	10	32	48	20	Loam
		50	32	48	20	Loam
		100	26	53	21	Silt Loam
1-1	2	50	33	47	20	Loam
		100	31	48	21	Loam
1-2	1	10	22	47	31	Clay Loam
		50	17	58	25	Silt Loam
		100	21	54	25	Silt Loam
1-2	3	10	16	54	30	Silty Clay Loam
		50	16	56	28	Silty Clay Loam
		100	26	51	23	Silt Loam
2-1	1	10	28	48	24	Loam
		50	26	50	24	Loam
		100	28	49	23	Loam
2-1	2	10	28	46	26	Loam
		50	31	46	23	Loam
		100	24	50	26	Loam
2-2	1	10	19	56	25	Silt Loam
		50	17	57	26	Silt Loam
		100	23	54	23	Silt Loam
2-2	3	10	11	59	30	Silty Clay Loam
		50	17	56	27	Silty Clay Loam
		100	16	60	24	Silt Loam
3-1	1	10	35	37	28	Clay Loam
		50	46	32	22	Loam
		100	35	36	29	Clay Loam
3-1	2	10	39	33	28	Clay Loam
		50	38	36	26	Loam
		100	42	32	26	Loam

Table 21. Continued

Channel	Run	Sample Station, in feet downstream	Percent Sand	Percent Silt	Percent Clay	Texture
3-2	1	10	41	32	27	Loam
		50	41	31	28	Clay Loam
		100	28	44	28	Clay Loam
3-2	3	10	40	32	28	Clay Loam
		50	43	30	27	Loam
		100	23	45	32	Clay Loam
4-1	1	10	73	16	11	Sandy Loam
		50	66	21	13	Sandy Loam
		100	51	33	16	Loam
5-1	1	10	14	58	28	Silty Clay Loam
		100	12	60	28	Silty Clay Loam
		200	11	63	26	Silt Loam
6-1	1	10	31	39	30	Clay Loam
		50	34	39	27	Loam
		100	34	39	27	Loam
7-1	1	10	52	28	20	Sandy Loam
		50	60	21	19	Sandy Loam
		100	61	27	17	Sandy Loam
8-1	1	10	82	7	11	Loamy Sand
		50	83	7	10	Loamy Sand
		100	75	9	16	Sandy Loam

Note: 1 foot = 0.305 m

APPENDIX F

Infiltration Excess Model for Storm Frequency Analyses

Consider a rainstorm distributed triangularly in time, with intensities ranked from highest to lowest, a maximum intensity of i_o, duration of T, and a total rainfall volume of P (see figure 21a). Then

$$P = \frac{(i_o)\ (T)}{2}$$

or

$$i_o = \frac{2P}{T} \qquad (12)$$

By similar triangles the intensity at any time t can be represented by

$$i = i_o - \frac{t}{T}\ i_o$$

or

$$i = \left(\frac{2P}{T}\right)\left(1 - \frac{t}{T}\right)$$

Suppose that this rainstorm falls on a uniform small watershed with a time constant infiltration rate of f (see figure 21b). The duration of excess rainfall (t_o) will be realized when f = i, or

$$f = \left(\frac{2P}{T}\right)\left(1 - \frac{t_o}{T}\right)$$

Thus

$$\frac{fT}{2P} = 1 - \frac{t_o}{T}$$

---

[7] From personal communication of April 1977 with Richard H. Hawkins, Associate Professor of Forestry and Outdoor Recreation at Utah State University

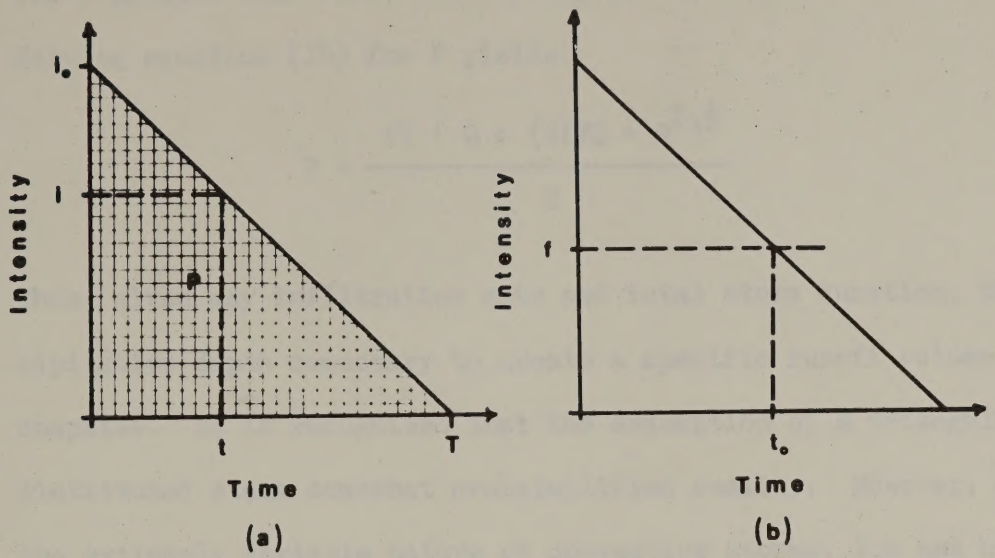


Figure 21. Intensity duration curves for the infiltration excess model

Solving for t_o yields

$$t_o = \left(1 - \frac{fT}{2P}\right)T \tag{13}$$

From figure 21b it is clear that the total excess rainfall, or runoff, can be represented by

$$Q = \frac{(i_o - f)t_o}{2}$$

Substituting equations (12) and (13) into the above equation and simplifying gives

$$Q = \frac{\left(P - \frac{fT}{2}\right)^2}{P} \tag{14}$$

Equation (14) is valid for the previously mentioned assumptions, for P greater than fT/2, and for any consistent set of units. Solving equation (14) for P yields

$$P = \frac{fT + Q + (2fTQ + Q^2)^{\frac{1}{2}}}{2} \qquad (15)$$

Thus, given any infiltration rate and total storm duration, the precipitation depth necessary to create a specific runoff volume can be computed. It is recognized that the assumption of a triangularly distributed storm somewhat oversimplifies reality. However, due to the extremely variable nature of convective storms, the use of an exponential or similar model would have required extensive analyses of individual summer storms. Because this study dealt with hypothetical storms rather than specific individual storms, the triangular model was considered adequate.

APPENDIX G

Results of Chemical Analyses
of Selected Water Samples Collected
During the Micro-channel Study

Table 22. Results of chemical analyses of selected water samples collected during the micro-channel study, corrected for control

Channel	Time, in minutes	Station, in feet	Ionic concentration, in milliequivalents per liter								
			HCO_3^-	CO_3^{2-}	Cl^-	SO_4^{2-}	Na^+	K^+	Li^+	Mg^{2+}	Ca^{2+}
			Results from run number one								
1-1	5	100	0.01	0.00	0.02	23.20	0.06	0.19	0.0039	0.00	21.62
	15	100	0.02	0.00	0.02	6.36	0.03	0.20	0.0009	0.00	6.78
	25	100	0.02	0.00	0.02	5.00	0.00	0.11	0.0004	0.00	4.79
1-2	5	100	0.01	0.00	0.05	14.45	0.41	1.22	0.0045	0.27	11.46
	15	100	0.00	0.00	0.05	10.17	0.13	0.14	0.0022	0.00	7.92
	25	100	0.00	0.00	0.01	9.44	0.06	0.12	0.0015	0.00	7.87
2-1	5	100	0.00	0.00	0.03	2.55	1.48	0.17	0.0047	0.00	2.76
	15	100	0.00	0.00	0.02	3.79	1.26	0.13	0.0036	0.00	4.25
	25	100	0.00	0.00	0.01	4.61	1.57	0.11	0.0053	0.00	3.03
2-2	5	100	0.00	0.00	0.04	1.35	0.05	0.11	0.0033	0.00	1.31
	15	100	0.00	0.00	0.08	0.00	0.00	0.08	0.0005	0.00	0.31
	25	100	0.00	0.00	0.02	0.00	0.00	0.12	0.0009	0.00	0.00
3-1	5	100	0.00	0.00	0.00	0.45	0.16	0.14	0.0011	0.00	0.43
	15	100	0.00	0.00	0.00	0.08	0.18	0.13	0.0008	0.00	0.94
	25	100	0.00	0.00	0.00	0.97	0.07	0.06	0.0000	0.00	0.64
3-2	5	100	0.01	0.00	0.02	0.00	0.03	0.00	0.0007	0.00	1.24
	15	100	0.00	0.00	0.00	0.00	0.00	0.00	0.0002	0.00	0.23
	25	100	0.00	0.00	0.03	0.00	0.00	0.00	0.0003	0.00	0.00
4-1	5	100	0.00	0.00	0.05	0.19	0.05	0.02	0.0000	0.00	0.71
	15	100	0.00	0.00	0.11	0.25	0.10	0.00	0.0000	0.00	0.23
	25	100	0.00	0.00	0.20	0.35	0.05	0.00	0.0000	0.00	0.25
	15	200	0.00	0.00	0.09	0.22	0.16	0.05	0.0010	0.00	0.60
	25	200	0.00	0.00	0.00	0.21	0.04	0.04	0.0000	0.00	0.52

Table 22. Continued

Channel	Time, in minutes	Station, in feet	Ionic concentration, in milliequivalents per liter								
			HCO_3^-	CO_3^{2-}	Cl^-	SO_4^{2-}	Na^+	K^+	Li^+	Mg^{2+}	Ca^{2+}
			Results from run number one (continued)								
5-1	5	100	0.00	0.00	0.20	10.63	0.06	0.07	0.0010	0.00	8.23
	15	100	0.00	0.00	0.00	7.09	0.05	0.00	0.0030	0.00	6.55
	25	100	0.00	0.00	0.00	3.90	0.00	0.00	0.0010	0.00	2.66
	40	100	0.00	0.00	0.01	2.38	0.00	0.00	0.0010	0.00	2.67
	60	100	0.00	0.00	0.00	2.70	0.01	0.00	0.0010	0.00	2.70
	5	200	0.00	0.00	0.11	14.13	0.07	0.11	0.0030	0.00	11.89
	15	200	0.00	0.00	0.03	13.43	0.07	0.08	0.0010	0.00	12.65
	25	200	0.00	0.00	0.00	6.39	0.00	0.00	0.0000	0.00	5.11
	40	200	0.00	0.00	0.00	4.55	0.00	0.00	0.0000	0.00	3.88
	60	200	0.00	0.00	0.00	9.30	0.00	0.00	0.0010	0.00	6.66
	15	300	0.00	0.00	0.00	13.23	0.00	0.09	0.0030	0.00	12.21
	25	300	0.00	0.00	0.00	8.17	0.07	0.04	0.0010	0.00	6.44
	40	300	0.00	0.00	0.03	4.80	0.01	0.00	0.0030	0.00	4.77
	60	300	0.00	0.00	0.00	12.93	0.00	0.02	0.0030	0.36	9.80
6-1	15	100	0.00	0.00	0.19	0.81	0.09	0.03	0.0000	0.00	1.08
	25	100	0.00	0.00	0.00	0.53	0.00	0.00	0.0000	0.00	0.53
7-1	5	100	0.00	0.00	0.06	0.14	0.07	0.10	0.0020	0.00	0.49
	15	100	0.00	0.00	0.13	0.00	0.00	0.01	0.0010	0.00	0.27
	25	100	0.00	0.00	0.20	0.00	0.02	0.02	0.0000	0.00	0.18
	40	100	0.00	0.00	0.00	0.06	0.00	0.00	0.0010	0.00	0.06
8-1	5	100	0.00	0.00	0.15	0.09	0.29	0.00	0.0000	0.00	0.11
	15	100	0.00	0.00	0.20	0.05	0.18	0.00	0.0000	0.00	0.01
	25	100	0.00	0.00	0.03	0.19	0.09	0.03	0.0000	0.00	0.00

Table 22. Continued

Channel	Time, in minutes	Station, in feet	Ionic concentration, in milliequivalents per liter								
			HCO_3^-	CO_3^{2-}	Cl^-	SO_4^{2-}	Na^+	K^+	Li^+	Mg^{2+}	Ca^{2+}
			Results from run number two								
1-1	5	100	0.01	0.00	0.01	13.74	0.03	0.02	0.0027	0.00	12.12
	15	100	0.01	0.00	0.00	6.92	0.01	0.01	0.0016	0.00	6.49
	25	100	0.02	0.00	0.00	4.23	0.07	0.01	0.0008	0.00	4.05
1-2	5	100	0.00	0.00	0.03	17.62	0.27	0.01	0.0045	0.52	15.92
	15	100	0.02	0.00	0.02	12.62	0.23	0.00	0.0032	0.00	11.32
	25	100	0.00	0.00	0.02	9.11	0.08	0.00	0.0021	0.00	8.85
2-1	5	100	0.01	0.00	0.09	10.19	4.09	0.01	0.0083	0.00	5.44
	15	100	0.01	0.00	0.03	10.99	1.71	0.01	0.0054	0.05	8.54
	25	100	0.01	0.00	0.02	6.99	1.34	0.00	0.0039	0.00	4.89
2-2	5	100	0.02	0.00	0.01	0.36	0.00	0.01	0.0012	0.00	0.70
	15	100	0.02	0.00	0.00	0.06	0.00	0.00	0.0000	0.00	0.60
	25	100	0.03	0.00	0.00	0.01	0.07	0.01	0.0000	0.00	0.60
3-1	5	100	0.03	0.00	0.01	0.29	0.14	0.01	0.0002	0.00	0.50
	15	100	0.07	0.00	0.01	0.09	0.00	0.00	0.0003	0.00	0.25
	25	100	0.07	0.00	0.02	0.16	0.09	0.00	0.0000	0.00	0.15
3-2	5	100	0.02	0.00	0.14	4.55	0.35	0.00	0.0022	0.00	4.40
	15	100	0.00	0.00	0.01	0.36	0.00	0.00	0.0003	0.00	0.65
	25	100	0.02	0.00	0.01	0.40	0.03	0.00	0.0000	0.00	0.80

Table 22. Continued

Channel	Time, in minutes	Station, in feet	Ionic concentration, in milliequivalents per liter								
			HCO_3^-	CO_3^{2-}	Cl^-	SO_4^{2-}	Na^+	K^+	Li^+	Mg^{2+}	Ca^{2+}
			Results from run number three								
1-1	5	100	0.03	0.00	0.00	4.12	0.00	0.13	0.0010	0.00	4.46
	15	100	0.06	0.00	0.00	3.06	0.00	0.23	0.0000	0.00	3.21
	25	100	0.06	0.00	0.00	2.05	0.04	0.25	0.0000	0.00	2.67
1-2	5	100	0.03	0.00	0.00	13.99	0.18	0.27	0.0020	0.00	9.99
	15	100	0.03	0.00	0.00	10.43	0.02	0.14	0.0020	0.18	8.09
	25	100	0.03	0.00	0.00	6.74	0.10	0.04	0.0000	0.04	5.29
2-1	5	100	0.00	0.00	0.05	6.79	2.17	0.09	0.0020	0.00	4.04
	15	100	0.01	0.00	0.03	6.28	1.55	0.12	0.0020	0.02	3.81
	25	100	0.05	0.00	0.02	4.80	0.96	0.08	0.0020	0.18	3.94
2-2	5	100	0.03	0.00	0.01	0.24	0.00	0.00	0.0020	0.00	0.39
	15	100	0.03	0.00	0.01	0.11	0.00	0.00	0.0000	0.00	0.71
	25	100	0.03	0.00	0.00	0.07	0.01	0.03	0.0010	0.00	0.13
3-1	5	100	0.03	0.00	0.00	0.36	0.10	0.10	0.0010	0.00	0.58
	15	100	0.03	0.00	0.00	0.27	0.02	0.00	0.0010	0.00	0.10
	25	100	0.03	0.00	0.00	0.08	0.00	0.23	0.0000	0.00	0.52
3-2	5	100	0.02	0.00	0.02	1.11	0.09	0.00	0.0000	0.00	1.37
	15	100	0.02	0.00	0.01	0.74	0.03	0.00	0.0010	0.00	0.90
	25	100	0.02	0.00	0.00	0.49	0.03	0.00	0.0000	0.00	0.73

Note: 1 foot = 0.305 m

VITA

Richard B. White

Candidate for the Degree of

Master of Science

Thesis: Salt Production From Micro-channels in the Price River Basin, Utah

Major Field: Civil and Environmental Engineering

Biographical Information:

Personal Data: Born 29 March 1952, son of Raymond H. and Marietta N. White; married Kathrine Blauer, 1974, one child--Elizabeth.

Education: Graduated from Yuba City High School, Yuba City, California, in 1970; received a Bachelor of Science degree from Utah State University, with a major in Watershed Science, in 1976; Completed the requirements for the degree of Master of Science, with a major in Civil and Environmental Engineering, at Utah State University, in 1977.

Professional Experience: March 1976 to June 1977, research assistant in Civil and Environmental Engineering at Utah State University; December 1975 to March 1976, teaching aid in Watershed Science at Utah State University; June 1974 to September 1975, forestry technician at the Intermountain Forest and Range Experiment Station, USFS, Logan, Utah.